LABORATORY EXERCISES IN PHYSICS

FULLER AND BROWNLEE

LABORATORY EXERCISES

TO ACCOMPANY

CARHART AND CHUTE'S FIRST PRINCIPLES OF PHYSICS

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PREFACE

In the preparation of a Physics laboratory manual, it is necessary to take into account the diversity of courses and equipment in different schools. The individuality of the teacher and the limitations of equipment have been recognized in the selection and treatment of topics, in these Exercises, and a wide choice of experiments has been provided, only a few of which require highly specialized apparatus. Where such apparatus is decidedly superior to that commonly used, specific directions for its preparation have been given in footnotes. Experiments which have proved their value in generally accepted courses have been retained with such simplifications as seem desirable to secure directness. Other experiments which represent the more modern trend in Physics teaching are introduced in considerable number to enrich the course.

Many students lose the value of the laboratory period because it is spent in following directions in a purely mechanical way, while they wonder why the particular problem on which they are engaged should be done at all. In order to settle this question in the student's mind, the authors have been in the habit of furnishing their students with an introductory paragraph for each experiment. This introduction connects the experiment with the pupil's experience and furnishes definitions of such terms as are necessary to the understanding of the directions. This introductory paragraph also permits the laboratory experiment on a particular topic to be given either before or after the subject is discussed in class, as the instructor may desire.

Following the plan of the best laboratory manuals, definite provision has been made for recording observations and calculated results either in tabulations or in simple diagrams. This plan permits the student's record to be made in a minimum time and leaves a larger proportion of the period available for actual laboratory work and the consideration of results than is possible when a running record is made. It also reduces the

time necessary for the instructor to judge the accuracy of the student's results, as well as his grasp of the principles involved.

The Conclusion always calls for a definite answer to the question which is raised in the Object of the experiment. Other important facts or principles which may be deduced in connection with the experimental work are subjects for questions in the Discussion. These may be answered orally as the instructor passes from student to student, or, in large classes particularly, the answers may be written in the note-book. In any case, these questions direct attention to the salient points of the experiment and should be taken up in the quiz on the laboratory work.

The authors wish to express their grateful appreciation of the assistance which they have received in the preparation of this book. Among their associates in the Stuyvesant High School they are particularly indebted to the principal, Dr. E. R. von Nardroff for valuable suggestions and for the stimulus which his interest in the experiments has afforded; to their colleagues in the Physical Science Department, particularly Mr. J. G. Baier and Mr. H. W. Mott, for many helpful criticisms and suggestions; and to Dr. H. E. Fritz, for valuable assistance in the preparation of the drawings. Many of the drawings have been made by the following students: Charles E. O'Rourke and Harold Jay, of the Stuyvesant High School, and John G. Smith, of the Geneseo Normal School. In connection with particular experiments, acknowledgment is made to the teachers who rendered assistance in these experiments. Thanks are tendered also to Professors Carhart and Chute for permission to use several cuts (Figs. 3, 35, 68, and 112) from the "First Principles of Physics"; to Professor W. H. Timbie for the use of the Resistance Table (p. 315) from his "Elements of Electricity"; and to the L. E. Knott Apparatus Company for the use of several cuts.

The authors will gladly receive criticisms and suggestions from teachers who may use the Exercises in their classes.

R. W. F.
R. B. B.

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INTRODUCTORY

SUGGESTIONS TO THE INSTRUCTOR

Selection of Experiments

Scope of the Experiments. — The experiments in this book provide a wide range of laboratory work for an elementary course in Physics. The exercises have been selected on the basis of their educational value to the student. Their aim is to impart to him certain fundamental principles, to acquaint him with some physical phenomena qualitative in character, and to show the operation and the use of practical devices or instruments that are applications of physical principles.

The authors have not hesitated to omit from their list certain well-known experiments which have persisted in many elementary courses, rather by inertia than because of any special interest or value to the beginner. On the other hand, it is impossible to include in a small book all the experiments of merit suitable to a first course in Physics. Yet, from those given, it will be possible for any instructor to make a selection of the experiments which the great majority of Physics teachers include in their courses, so as to afford a well-balanced laboratory training, both interesting and instructive to the student.

Recommended Lists. — Only the institutions most favored as to laboratory time will be able to complete in one scholastic year all the experiments outlined in this book. Any choice of experiments must depend upon the apparatus available and upon the laboratory conditions. To fit the usual laboratory equipment and to meet the time limitations of most first courses in the subject, the authors suggest the following list of thirty-five experiments as affording a good training in those

fundamentals of the science most suitable for laboratory in struction:

Fundamental Course

Mechanics: Exercises 3, 4, 5, 8, 9, 10, 11, 19, 23, 25, 26, 27.
Sound: Exercise 35.
Light: Exercises 37, 38, 39, 42, 43, 46 *A*, or 46 *B* and 47.
Heat: Exercises 51, 58, 59, 61, 62.
Magnetism and Electricity: Exercises 66, 68, 69, 70, 80, 81, 82, 83, 84, 85, 89.

The following ten exercises will supplement the above, particularly for those students whose ability enables them to do a maximum amount of work:

Mechanics, 6, 13 or 14, 28, 29;
Sound, 34;
Light, 44;
Heat, 57;
Magnetism and Electricity, 72, 78 (or other experiment on resistance), 90.

The following sixty exercises are suggested as a more extended course for those institutions favored with about double the laboratory time usually allotted to the first course:

Extended Course

Mechanics: Exercises 1, 3, 4, 5, 8, 9, 10, 11, 15, 16, 17, 19, 20, 23, 24, 25, 26, 27, 28, 29, 30.

Sound: Exercises 32, 34, 35.

Light: Exercises 37, 38, 39, 42, 43, 44, 46 *A*, or 46 *B* and 47, 48.

Heat: Exercises 51, 52, 57, 58, 59, 60, 61, 62, 63.

Magnetism and Electricity: Exercises 65, 66, 68, 69, 70, 72, 73, 78, 79, 80, 81, 82, 83, 84, 85, 86, 89, 90.

The authors recommend the following list of experiments for girls, especially for those not intending to go beyond the high school. Most of these experiments have been selected because of their close relationship to the practical affairs of life.

Mechanics: Exercises 1, 2, 3, 6, 8, 9, 12 (or 13 or 14), 17, 18, 23, 26, 27, 28.

Sound: Exercises 34 (or 35), 36.

Light: Exercises 37, 38, 39, 49, 50.

Heat: Exercises 51, 52, 59, 60, 61, 64.

Magnetism and Electricity: Exercises 65, 68, 70, 79, 80, 82, 83, 84.

A number of interesting and valuable experiments do not appear in any of the preceding lists, but it is hoped that some of them will be taken from time to time either as substituted or as additional exercises. A limited amount of variation from year to year adds interest and vitality to any laboratory course. Many of the experiments just referred to will meet the needs of those instructors who desire to give more time to certain divisions of the subject.

Order of Experiments. — The order in which the divisions of the subject are taken should depend upon the aim of the course and the conditions under which it is given. In their own work the authors find the most satisfactory order to be Mechanics, Heat, Sound, Electricity, and Light. In most syllabi, however, the subject of Light precedes that of Electricity. In the view of many, the experiments on Heat are best adapted to the student's powers after he has finished the experiments in Mechanics.

Time required for Experiments. — A majority of the experiments are designed to take from 80 to 90 minutes of laboratory time, including the writing of the note-book record. Some of the shorter ones will require but half of that time, or a single school period. Even if a double laboratory period is not available for the longer experiments, the directions have been written so that the experiments can be done successfully in two single periods. The system recommended for the note-book record saves time in securing the observational data. Especial care has been taken not to overload the student with more manipulations and observations than would be reasonable for an average rate of work within the time allotment.

The Experimental Directions

Aim. — At first sight it may seem that the directions for the experiments have been written in a rigid form which may hamper the individuality of the teacher using them. With the possible exception of the placing of the tables of observations and calculated results, it will be found that the directions and their requirements are in accord with the usages which have become generally established as leading to intelligent and efficient laboratory work.

The five main divisions of the printed directions are "Introductory," "Experimental," "Calculated Results," "Discussion," and "Conclusion." Certain suggestions as to these divisions appear in the paragraphs that follow.

Introductory. — The paragraphs under this heading in the printed directions serve several purposes. First, they awaken the student's interest in the problem to be studied by reference to applications of Physics more or less familiar to him. Secondly, the introductory statements show the relation between the practical applications and the laboratory problem to be solved. In some cases the paragraphs furnish a little theoretical information, necessary for the intelligent performance of the experiment. All that is required of the student is that he read and understand this introductory matter — usually a task of a few minutes. It is not expected nor is it desired that the introductory matter be copied into the note-book.

The authors offer no apology for the paragraphs introductory to the experiments. They have simply put in written form those preliminary remarks that many instructors find desirable to make when the class assembles for the experiment. It is felt that the written form has the advantage of being always available for the student's reference.

Experimental. — Whenever the length and character of the experiment permits, the laboratory problem is presented as a whole to the student. With the general plan in mind, he is able to do the experiment with greater self-reliance and effi-

ciency than can be obtained from the slavish following of detailed directions with little grasp of their intent.

In some experiments, however, detailed directions must be given to secure the successful imparting of a series of experimental facts. In such cases the divisions are made as few as possible and their meaning made clear by brief directions, a little supplementary information, and questions that the average student should be able to answer from his experimental observations.

The students are directed to place the data gathered in the experiment in a *table of observations* near the top of the *left-hand* page of the note-book record. The form for this table is usually furnished, and it is strongly recommended that the student write the form in the note-book before making any of the measurements. This procedure provides for the orderly recording of the data as soon as it is obtained, and insures the completion of the experimentation within the laboratory hour. There is economy also of the instructor's time, as he can quickly note the rate of progress of the individual and check inaccuracies in the readings.

With most experiments only one set of readings is indicated in the tables of observations, but the instructor desiring more can increase the number of columns at the right. In the opinion of the authors, much time is wasted by requiring the duplication of readings by the elementary student of Physics, unless in work where personal errors are large.

Drawings. — After the observations are completed, the student is directed to make sectional or outline drawings from his apparatus so as to show that he understands its arrangement and operation. Many of the illustrations in this book have been made from drawings made by students in the regular course of their laboratory work. Such drawings will indicate to the users of this book the methods of representing laboratory apparatus by simple outline drawings. The development of a simple scheme of sectional representation is within the power of any student and will prove most useful to him.

Descriptions. — The table of observations and the sectional drawings render unnecessary long and elaborate descriptions of the experimental work. All that is asked is a brief but clear statement of the general method of the experiment and the recording of any experimental facts not shown by the drawings nor provided for in the table of observations. In the last few years it has become more and more recognized that the chief function of the laboratory note-book is to show the essentials of an experiment and not to provide useless drudgery for the student.

Calculated Results. — Preceding the table of calculated results occurring in many experiments, are found directions for making the calculations. The authors have not hesitated to furnish information to aid the student in making the calculations when these are rendered more intelligible thereby.

The directions call for the placing of the *table of calculated results* at the top of the *right-hand* page of the note-book record. The calculations themselves should be made directly below the table. These requirements secure prominent and convenient locations for the making of the computations and the orderly recording of the results. The student can tell from the tabular form what is expected of him in the way of calculations and knows when his work is finished. The instructor is enabled to check quickly the recorded results and to point out during the laboratory period sources of error.

Discussions. — Under this division the student is directed to answer any italicized questions occurring in the experimental directions or the questions under the printed heading, Discussion. Thus the theoretical considerations of the experiment are brought together ready for reference or correction.

Conclusions. — The student is either required to state for himself the formal conclusion justified by the experimental facts, or to complete a partial statement by filling in the indicated blanks. The latter method is preferred in those cases where a complete and well-worded conclusion is difficult for

the student to formulate. The vital part of the statement must be furnished by the student and requires thought on his part.

Method of Laboratory Work. — Many of the advantages of having the note-book record follow a definite plan have been discussed under the topics preceding this. Tabular forms for the observations and the calculated results are appreciated by many instructors as leading to that economy of laboratory time which gives the best opportunity for experimentation and reflection. The forms for such tabulations may be written in the note-book prior to the laboratory hour and the general plan of the experiment studied.

The authors believe that it is not only permissible, but highly desirable, for the student to know before he comes into the laboratory what he is to do. They require their own students to carefully study the experiment and to write the blank table of observations in the note-book before coming to the laboratory. Except in the case of very complicated experiments, the student is not allowed to have the experimental directions before him until he has taken all readings and completed his drawing and description. He is then allowed to refer to his direction sheet for guidance as to his calculations and conclusions. It has been found that under this plan the work in the laboratory is more intelligent and less of the "cook-book" order. Furthermore, schools having only single laboratory periods may be certain of having the readings taken and the experiment described during the laboratory period, while calculated results and conclusions may be worked out the next day either in laboratory or classroom, or, if desired, done as part of the home lesson for the day following that of the laboratory period.

No factor contributes more to the success of a laboratory course than having the apparatus tested and entirely ready for the student when he enters the laboratory. Then only is it possible for him to put the apparatus together and start its operation without loss of time, so that the readings can be made comfortably within the period.

Note-book Directions. — On page 16 there will be found brief instructions intended for the student and relating to the form of the note-book record. Any orderly plan must have definiteness; so it becomes necessary to designate left-hand and right-hand pages for certain purposes. These directions may reverse the usage of some instructors, but it is hoped that they will realize it makes little difference whether the left-hand page or the right-hand page serves a certain purpose, so long as there is a definite systematic plan to make the note-book record a help to the student, and to make the ever present and laborious task of note-book correction easier for the instructor.

DIRECTIONS TO STUDENTS

Balances

Construction of Platform Balances. — The platform balance or trip scale is a simple, equal arm lever in which the vertical displacement of either arm is indicated by a pointer swinging across a horizontal scale. When the pointer swings approximately equal distances on each side of the center division on the horizontal scale, the two lever arms are balanced and the scale is said to be in equilibrium.

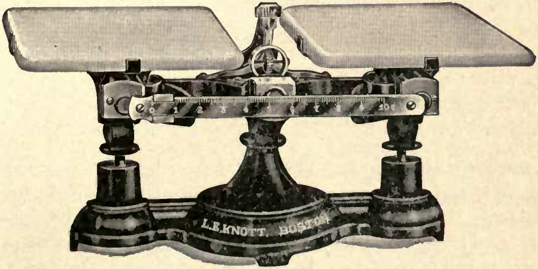

Fig. 1. Platform Balance.

The construction of the trip scale is shown in Figs. 1 and 2 on this and the following page. This convenient instrument for weighing is too often misused in the physical laboratory and poor results obtained with it. With the observance, however, of a few simple precautions, rapid, accurate weighings can be made with this piece of apparatus.

Adjustment of Platform Balances. — Before weighing always see that both platforms are clean Then touch lightly one

platform and note whether or not the pointer swings freely and equally on each side of the center line of the scale. The pointer should oscillate at least two divisions to the right and to the left. In too short swings the friction in the bearings makes the scale relatively less sensitive. Therefore the pointer's coming to rest at the center point is no sure indication that the two arms of the scale are balanced or in equilibrium.

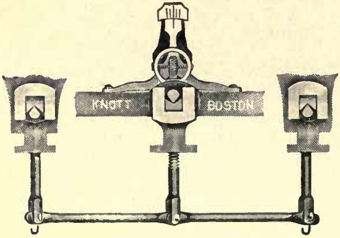

Fig. 2. Sectional View of Balance.

In case the pointer swings to a distinctly greater distance on one side of center, turn the thumb nut which is just below the center, so that the nut moves a little distance towards the side of the lesser swing. Again note the swings. When they are approximately equal on both sides of center, the scale is adjusted for weighing.

Handling of Weights. — Place the *object* to be weighed on the *left-hand* platform or pan and the *weights* on the *right-hand* platform. In adding or removing weights, prevent with the left hand the movement of the pans until the change of weights has been made. In this way avoid jarring the balance and injuring the knife-edges.

For the first weight select the one which in your opinion is about equal to the object being weighed. If this weight is too small, take it off and replace it with the next larger one. Continue in this way until you have the largest weight which is lighter than the object. Then add the next smaller weight. Time-saving weighing means the systematic use of the next smaller or the next larger weight, as the case may be, until the scale is balanced.

In practice the graduated beam with its rider enables one to

dispense with the smaller weights. If the beam is graduated for 5 grams, the 1-gram and the 2-gram weights are not used; with a 10-gram beam, the weights below 10 grams are not necessary. By means of the graduated beam, these smaller weights are found by moving the rider to the right until the balance is in equilibrium. Note carefully on which side of the rider the reading should be made, and remember that the reading can be made to *tenths* of a gram.

When the correct weight is obtained, count carefully the weights on the right-hand pan and add the weight indicated on the beam. Record this total weight at once in the laboratory note-book.

Return the weights to their block, or case, counting as you do so. Add the weight indicated on the beam and check the weight recorded in the note-book. Remove the object from its scale pan. A scale left with the arms unequally balanced soon loses its sensitiveness, owing to unnecessary wear on the bearings.

Beam Balances. — Another form of balance much used in the physical laboratory is the beam balance. The beam in this case rests at its center point on a knife-edge, or a wedge, supported on a vertical stand. Pans are suspended on the ends of the beam either by hooks, or in the more expensive kinds by stirrups which rest on knife-edges. A vertical pointer indicates on a small graduated scale the oscillations of the beam. Some beam balances have on one arm of the beam a rider, which slides along a graduated scale and thus indicates the smaller weights. To avoid dulling the knife-edges, there is often a device which lifts the beam off the knife-edges when the balance is not in use. The pan arrest similarly lifts the bow and stirrup suspension from off the knife-edges on the ends of the beam.

The *specific gravity balance* is usually a beam balance which has a shorter suspension for one of the pans. From a hook on the under side of this pan are suspended objects which are to be weighed in a liquid.

The *hornpan balance* is simply a beam balance, which is supported vertically from a hook hung on a ring stand or held by the hand.

Spring Balances. — A spring balance measures the mass of a body by the elongation of a spiral spring. The weight is indicated on a graduated scale by a pointer attached to a drawbar on the free end of the spring. Attached to the drawbar is a hook on which is suspended the object to be weighed.

The spring balance is made to read correctly in vertical position, with the hook downward. The weight of the drawbar and hook should be sufficient to bring the pointer to the zero mark on the graduated scale. If the pointer does not stand at zero with no load on the balance, a correction must be made to the weight registered on the scale in order to get the true weight of the object. The inconvenience of making these corrections may sometimes be avoided by wrapping about the shank of the hook a strip of sheet lead, sufficient in weight to bring the pointer to the zero point of the scale.

The friction in a spring balance tends to make less accurate the readings in the first portion of the graduated scale. At the other end of the scale, when the spring is near its maximum stretch, the elongations are not quite proportional to the heavier weights added. Accordingly the most accurate readings with a spring balance are those obtained in about the middle portion of the graduated scale.

In some experiments the spring balance is used to measure the pull or force exerted upon its spring. When used for this purpose it is termed a *dynamometer*.

Sensitiveness of a Balance. — The sensitiveness of a balance may be defined as the smallest difference which is indicated by the balance with a given load. The trip scale should be sensitive to at least the tenth of a gram with an ordinary load, *i.e.* show a difference between 50.6 and 50.7 grams. A good hornpan balance indicates weights within the hundredth of a gram (1 centigram) while an accurate chemical balance is sensitive to a ten-thousandth of a gram (tenth of a milligram).

Relative Advantages of Platform and Beam Balances. — The platform balance, while it is easy to keep clean and can stand much usage, is usually not so sensitive as the beam balance. The broad platforms, however, are very convenient for weighing bulky, unstable objects, and the oscillations of its beam are easily controlled.

The sensitiveness of a beam balance is gained at the expense of stability and durability, for the beam is easily displaced and the knife-edge suspension becomes dulled by use. On this account great care should be taken not to jar the balance nor allow the beam to oscillate too rapidly. The weights should be placed gently upon the pans and removed when the pans are at rest (*i.e.* supported by the pan arrest or by the hand).

Were it not for the awkwardness and carelessness of some students, the beam balance would always be most desirable for rapid, accurate weighings in the physical laboratory.

Electrical Measuring Instruments

The instruments used for measuring the strength or the pressure of an electric current have very delicate parts and may be easily ruined by either rough usage or excessive current.

Before using any galvanometer or other meter the student should assure himself that it has the proper scale range and current-carrying capacity for the work in hand. He must further so connect his apparatus that the instrument will not be upset or pulled out of place by any change in connections made during the experiment. As the several instruments that the student may be called to use in his experiments differ in their sensitiveness, method of connection, and method of reading, each kind will be briefly discussed by itself. In reading all instruments, tenths of the smallest divisions should be estimated.

Tangent Galvanometer. — This consists of a compass needle mounted at the center of a hoop, on which is wound the wire

which is to convey the current. This is the most rugged of the instruments, but the pivot is likely to be bent by dropping or violently jarring the instrument. Where there are a number of binding posts, to permit the use of different numbers of turns of wire, find out from the instructor which posts to use and the number of turns of wire included between them. In order to read the instrument accurately, it should be so placed on the table that it will be possible to look directly down on the needle. The instrument should be carefully turned until the needle is in the plane of the coil.

D'Arsonval Galvanometer. — The moving part of this instrument is a light coil of wire, suspended between the poles of a permanent magnet by a fine wire or ribbon through which the current passes. This suspension is exceedingly thin, so that even a slight shock to the instrument will break it and a comparatively small current will melt it. The instrument is commonly provided with a clamping device which takes the weight of the coil off the suspension when the galvanometer is not in use.

In setting up the galvanometer, keep the coil clamped until you are ready to connect to the source of current. Then make sure that the instrument is leveled in such a way that the coil does not rub against any part of the instrument but hangs perfectly free. The method of reading the deflections for the particular instrument you are using will be explained by the instructor.

It is exceedingly important that only a *very small current* pass through the coil of the instrument. On this account, the galvanometer should have either a coil of high resistance in series with it or a low resistance shunt across the terminals for most experiments. Such additions to the instrument should be made either by the instructor previous to the laboratory hour or under his immediate direction by the student.

Ammeter. — The commercial form of this instrument is usually a d'Arsonval galvanometer provided with a shunt of

such resistance that the deflections of the needle give the number of amperes directly. The coil is pivoted instead of being suspended, but the instrument must be guarded against falls and shocks just as a fine watch would be.

Before connecting the ammeter in circuit, be sure that its range is sufficient for the current to be measured. If the instrument has more than one range, always connect for the largest range first, and then change the connections to those for a smaller range, if the readings indicate that this can be safely done.

If the ammeter has an *external shunt*, be sure that the connections between the shunt and the instrument movement are tight. A loose contact will certainly make an incorrect reading and may burn out the instrument.

Connect the terminals of the instrument *in series* with the circuit. If connected in shunt with the other apparatus, the resistance of the instrument is so small that the movement will probably be burned out.

In every electrical circuit, there should be a switch that can be opened instantly if there is the slightest indication of too much current for the instruments or any other part of the apparatus.

Voltmeter. — This is similar to the ammeter in construction, but has a high resistance in series with the movement instead of a shunt across the movement. The voltmeter measures pressure, while the ammeter measures current flow.

The same precautions for handling and for the selection of a proper scale range are to be observed as in the case of the ammeter.

Connect the voltmeter *across* (in shunt with) the circuit or that part of the circuit in which the voltage drop is to be measured.

Resistance Box. — The voltage applied to a resistance box should never be great enough to cause more than 0.1 ampere to pass through the box.

The Laboratory Note-book

Unless other directions are given by the instructor, the following plan should be followed in recording experiments in the note-book.

Number of Experiment. — Place to the left and at the top of the *left-hand* page.

Date of Experiment. — Place to the right and at the top of the left-hand page.

Title. — Place immediately below the number and date.

Object. — Place directly below the title.

Tables of Observations. — Place immediately below the object. In case the instructor desires the duplication of the observations, make the necessary number of parallel columns at the right. Always record the measurements, *as soon as made*, in the tabular form. Decimals should be used, rather than common fractions.

The number, the date, the title, the object, and the table of observations should be written in the note-book *before* the experimental work is begun.

Drawings. — Place on the left-hand page clear sectional drawings showing the arrangement and operation of your apparatus. In making a sectional drawing, imagine a vertical plane passing through the middle of your apparatus; then imagine your paper to be in the position of this plane. Draw lines where the paper would touch the intersected apparatus.

Descriptions. — Place these usually on the left-hand page and shorten your work by referring to your drawings. A simple, clear account of the general method of the experiment is preferable to an elaborate description.

Table of Calculations. — Place at the top of the *right-hand* page *before* making any of the calculations. Do the mathe-

matical work involved, immediately below the table, and record the results *as soon as obtained* in the tabular form.

Discussion. — Under this heading on the right-hand page, answer any italicized questions occurring in the experimental directions as well as the questions under the printed heading of "Discussion." If more room is necessary, continue on the *next* right-hand page.

Conclusion. — Place under this heading on the right-hand page, immediately following the Discussion.

Introductory. — It will pay you to read and understand this, before beginning the experimental work. It is not to be copied into the laboratory note-book.

LABORATORY EXERCISES

EXPERIMENT 1

Metric Units of Measurement

OBJECT. To become familiar with the units of metric measurements commonly used in scientific work.

APPARATUS. Meter stick; scissors; small graduate (50 or 100 c.c.); large graduate (500 or 1000 c.c.); liquid quart measure; small wide-mouth bottle; tumbler; platform balance; metric weights; 1 lb. weight.

MATERIAL. "Oak tag," or some other kind of stiff paper; mucilage, or paste.

Introductory:

The Metric System is the official system of units of measurement in most civilized countries. It is the system used in scientific work in the United States. The unit

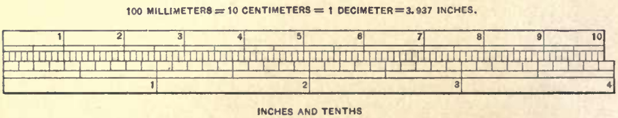

Fig. 3.

of this system is the *meter*, and standard bars with this distance marked on them are preserved for reference by various governments.

The Metric System is a decimal system and therein lies its great convenience. The meter is subdivided into

ten parts, each of which is termed a *decimeter;* the hundredth of a meter is a *centimeter;* the thousandth of a meter, a *millimeter.* From these fundamental units, the units of surface, volume, and weight are derived.

The meter measures 39.37 inches.

Experimental:

At the top of the *left-hand page* of the laboratory note-book put the *number* and *title* of the experiment and the *date.* Then state the *object* of the experiment. Immediately below this, put the following tabular form for the readings:

OBSERVATIONS

Length of note-book cover	*cm.*
Width of note-book cover	*cm.*
Metric equivalent of liquid quart	*cm.*^{3}
Capacity of small bottle	*cm.*^{3}
Capacity of tumbler	*cm.*^{3}
Weight of note-book	*g.*
Metric equivalent of a pound	*g.*

Units of Length. — (*a*) Examine a meter stick, noting its subdivisions. In your laboratory note-book, just below the table of observations, rule horizontal lines of the following lengths, labeling each line with its length:

1 decimeter, 1.1 decimeters, 1.5 decimeters, 5 centimeters, 2.5 centimeters, 1.3 centimeters, 1 centimeter.

(*b*) Measure in centimeters and tenths of a centimeter the length of the cover of your laboratory note-book. Similarly measure the width. Record the dimensions.

Units of Volume and Capacity. — (*c*) On a separate piece of paper, lay off a diagram like Fig. 4.

Cut around the diagram with a pair of scissors. Bend over the little flaps and fold into a cube, pasting the flaps on the inside so as to hold the cube together.

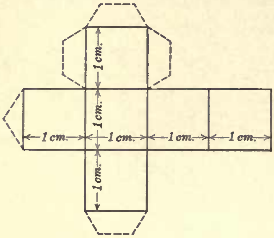

Fig. 4.

The little cube, if accurately made, is a *cubic centimeter*, the unit of volume. 1000 cubic centimeters give the *liter*, the unit of capacity. For convenience, the measuring instruments for liquids are usually cylindrical vessels, marked off in cubic centimeters and known as *graduates*.

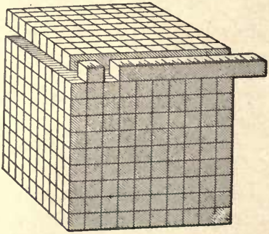
Fig. 5. Dissected Liter Block.

(*d*) Using a large graduate, determine how many cubic centimeters of water are needed to fill an ordinary quart measure.

(To be done in groups of four students unless otherwise directed by the instructor.)

(*e*) Using a small graduate, find the capacity in cubic centimeters of the small bottle furnished you.

Similarly determine the capacity of an ordinary drinking tumbler.

Units of Weight. — The weight of a cubic centimeter of water at its maximum density (4° C.) is taken as the unit of weight, the *gram*.

1000 grams make a *kilogram*, a weight used for measuring large quantities.

(*f*) Using a platform balance, find the weight in grams of your laboratory note-book. Record.

(*g*) Determine how many grams are needed to counterbalance an ordinary pound weight. Record.

Tables for the calculated results should be placed at the top of the *right-hand* page of the note-book, and the calculations worked out just beneath them.

Express the number of cubic centimeters found in (*d*) as the decimal part of a liter. Using this number, calculate the equivalent of a liter in quarts, carrying the result to two decimal places.

Calculate from the comparison of weights found in (*g*), the equivalent of a kilogram in pounds and tenths of a pound.

CALCULATED RESULTS

1 *liter* . . . . *qts.*
1 *kilogram* . . . . *lbs.*

Discussion:

In what respects was the convenience of the Metric System shown in your measurements? Place the answer to this question on the right-hand page of the note-book, heading it "Discussion." (Under this heading are to be written the answers to any italicized questions occurring in the experimental directions.)

EXPERIMENT 2

Properties of Materials

OBJECT. To examine a few common substances so as to determine their properties.

APPARATUS. Triangular file; pocket-knife; hammer; anvil, or flatiron (with detachable handle).

MATERIAL. Copper wire #18, or some larger size; strips of sheet lead about $3\frac{1}{2}'' \times \frac{1}{2}''$; pieces of small glass tubing; paraffin; rubber bands, or strips of sheet rubber; steel nails.

Introductory:

Every substance has its own set of properties. Certain of these are the well-marked or characteristic properties by which we recognize the substance. These characteristic properties are important in that they determine the practical use of a substance.

Experimental:

The substances to be examined are copper, glass, rubber, lead, paraffin, wood, and steel. Take them in any order. Tabulate on the left-hand page of your note-book the results of your examination, in a table like that given below.

SUBSTANCE	HARDNESS	LUSTRE	MALLEABILITY	ELASTICITY
Copper				
Glass				
Rubber				
Lead				
Paraffin				
Wood				
Steel				

Hardness. — Use a knife blade or a file to determine the hardness. Describe this in comparative terms, as very soft, soft, somewhat hard, hard, and very hard.

Lustre. — Note two kinds of lustre or "shine." Which substances would be said to be without lustre?

Malleability. — Use a hammer, and tap the substance on an anvil or other block of iron to ascertain whether or not the substance can be hammered out into sheets without breaking.

Elasticity. — Try to change the shape of the substance by bending. If the substance bends or gives, remove the strain to find out whether or not the substance will return to its original condition. In determining the elasticity, make use of the results obtained in testing for malleability.

Ductility. — A ductile substance admits of being drawn out into fine wire. This property is not easily determined in the laboratory by students. *Which of the substances are ductile? Why do you think so?* Do not tabulate for ductility.

Write a simple description of how you determined each of the properties tabulated. No drawing is necessary for this experiment.

Discussion:

Under this heading on the right-hand page of notebook, answer any italicized questions occurring in the experimental directions, and also the following questions: Which of the substances are good conductors of heat? Of electricity? Name any other general properties that have not been mentioned in this experiment (Class Discussion).

EXPERIMENT 3

Measurement of Bodies

OBJECT. **To find in metric units the volume of a block of wood.**

APPARATUS. Wooden block; metric scale.

Introductory:

Iron is "heavier" or more dense than wood. To find out how many times as dense, measurements must be made of the size and weight of a piece of each. It is more convenient in physical work to make the measurements in the metric system, because it is a decimal system. The chief units used are the centimeter and the gram.

Experimental:

On the left-hand page of your note-book and immediately below the statement of the object of the experiment, put a tabular form like the following for the measurements to be made:[1]

OBSERVATIONS

Number of block	
Length of block	*cm.*
Width of block	*cm.*
Thickness of block	*cm.*

When the scale is placed so that the scale divisions touch the block, there will be less error in reading measurements.

[1] *Note to Instructor.* Many teachers find it desirable to have the students write in their laboratory note-books, previous to coming into the laboratory, the number, the title, and the object of the experiment, and any tabular form of measurements to be made. As this will be the first experiment in many courses, the directions for the note-book record have been made very definite.

The eye must be directly in front of the point on the scale and the point located in the block. *Why is it desirable to estimate to hundredths of a division on a scale divided into tenths?*

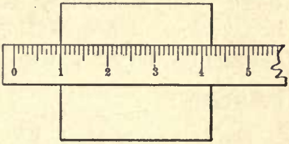

Fig. 6.

Using the scale in this way, find the length, breadth, and thickness of the block furnished you. Do not make measurements at bruised corners.

From your apparatus make, on the left-hand page of the note-book, an outline drawing similar to that given (Fig. 6).

On the same page write a brief description of what you did, touching on the points regarding measurements which you were instructed to observe. Complete in the laboratory at least the drawing and the description. The left-hand page of the note-book should be finished before the right-hand page is begun.

On the right-hand page, place the table of calculated results, the calculations themselves, the answers to the questions for discussion, and the formal conclusion. The tables of calculated results should always be placed at the top of the right-hand page.

Calculated Result

Volume of block . . . . *cm.*^{3}

In making the calculations for the above results, indicate the units of measurement for each result. Do not carry out the calculated volume beyond the hundredths of a cubic centimeter. Read the discussion on "Significant Figures," pages 27–29.

Discussion:

Under this heading on the right-hand page answer any italicized questions occurring in the experimental directions. Why would it be desirable to make several measurements of each dimension of the block and take the average for the calculation?

Conclusion:

The volume of block No. ..... is ...... $cm.^3$.

SIGNIFICANT FIGURES

Accuracy in Scientific Calculations. — Calculations in scientific work are based on readings obtained by some method of measurement. The calculations cannot be more accurate than the figures with which they are made. Yet beginners in physics, in their zeal to be accurate, retain figures in their calculations far beyond the point justified by the accuracy of the measurements. The results are not so accurate as they would be if certain figures had been discarded in the progress of the calculations. The following paragraphs aim to show how *scientific* accuracy may be obtained in the calculations of experimental physics.

Average Readings or Results. — The dimensions of a rectangular block may be measured with a metric scale graduated in centimeters and millimeters. By estimating the tenths of a millimeter, the readings may be expressed to the hundredths of a centimeter.

The following readings might be obtained for the length of the block as determined along two of its edges:

A	*B*
7.45 cm.	7.45 cm.
7.42 cm.	7.42 cm.
7.47 cm.	7.47 cm.
3)22.34 cm.	3)22.34 cm.
7.44 cm.	7.446 cm.
(Correct scientific average.)	(Incorrect scientific average.)

The second decimal place in these readings represents the estimated tenths of a millimeter. In estimating such small quantities, one may readily misjudge not only by one tenth of

a millimeter, but even to the extent of two or three tenths. Hence the figures expressing tenths of a millimeter are not accurate, but are doubtful figures. They are indicated here in heavy-face type.

In column *B* the average given for the three readings is 7.**446**. In this number the second **4** is a doubtful figure, therefore the **6** in the next decimal place beyond must be *more than doubtful.* This figure **6** means nothing in our units of measurement.

Some authorities may claim that 7.45 is nearer to the correct average in such a case. Mathematically this is so, but it must be remembered that one cannot judge accurately between 0.04 cm. and 0.05 cm. on a scale whose smallest division is 0.1 cm. Hence the average of 7.4**4** in column *A* may be regarded by the painstaking student as correct and reasonable, particularly as the divisor is a small number.

Retention of Significant Figures. — Let us find the volume of a rectangular block with the following dimensions: length, 7.4**4** cm.; width, 4.6**7** cm.; and height, 2.8**2** cm. To find the area of the base multiply the length by the width, indicating the doubtful figures in heavy-face type.

```
   7.44
   4.67
   5208
  4464
 2976
34.7448 cm.²
```

In the first partial product, **5208**, all the figures are doubtful, as they were obtained by multiplying by the doubtful figure **7**; in the second partial product, 446**4**, the final **4** is doubtful because it resulted from a multiplication in which a doubtful figure was a factor; and for the same reason the **6** in the third partial product, 297**6**, is doubtful.

In the addition of the partial products, figures which are ob-

tained by adding doubtful figures, are doubtful figures. This makes the last four figures doubtful in the total 34.**7448**. All the doubtful figures but the *first* should be discarded. Then the area of the base as justified by the accuracy from measurements is 34.**7** square centimeters.

To find the cubical contents multiply the area of the base by the height:

$$\begin{array}{r}
34.\mathbf{7} \\
\underline{2.8\mathbf{2}} \\
\mathbf{694} \\
277\mathbf{6} \\
\underline{694} \\
97.\mathbf{854}\ \text{cm.}^3
\end{array}$$

Discarding all the doubtful figures except the first, 97.**8** cm.^{3} is the correct volume of the rectangular block.

A student who found the cubical contents without discarding any of the doubtful figures would get as a result 97.980336 cm.^{3}. Not only would he have done extra work, but his result would not be scientifically accurate.

A good rule in making calculations is to *retain only significant figures.* Significant figures include the first doubtful figure and the figures preceding it.

EXPERIMENT 4

Volume Measurement of an Irregular Body

OBJECT. To find the volume of a body of irregular shape.

APPARATUS. Solid of irregular shape, as a lump of metal, brass hook weight (50 or 100 g.), or large-sized lead sinker; cylindrical graduate (100 c.c.); strong thread, or string.

Introductory:

The volume of a body of irregular shape cannot be found by measuring a few dimensions and then making a simple calculation. A stone dropped into a glass of water raises the water level. As the stone and the water cannot occupy the same place at the same time, the volume of the stone may be found from the *increase* in volume.

Experimental:

Given a lump of metal and a graduated cylinder with water in it, devise a way of getting the volume of the metal.

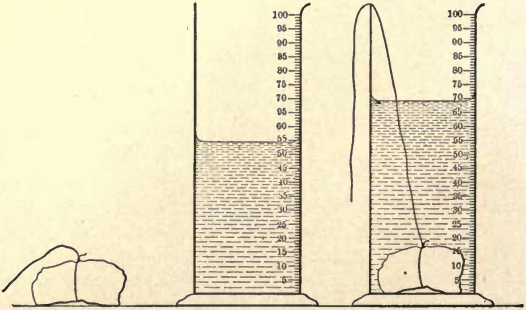

Fig. 7.

In reading a graduate, place the eye on the level of the lowest point of the curved surface and record this as the height of the water. As the graduations are cubic centimeters, and as an error of 1 $cm.^3$ in the volume that we are measuring would be a considerable per cent of error, therefore, estimate tenths of a cubic centimeter as nearly as you can.

Make the readings indicated by the table of observations and record in a similar tabular form near the top of the left-hand page of note-book.

OBSERVATIONS

Reading before immersing the metal . . .	*cm.*^{3}
Reading after immersing the metal	*cm.*^{3}
Number of lump of metal	
Material of lump	

On the left-hand page of the note-book, make from your apparatus, outline drawings similar to Fig. 7, and write a simple description of the experimental method used.

Discussion:

What property of matter makes possible this method of finding the volume?

Conclusion:

Volume of lump of metal No. _____ is _____ $cm.^3$ – _____ $cm.^3$ = _____ $cm.^3$.

EXPERIMENT 5

Density

OBJECT. To determine the density of wood and of metal.

APPARATUS. Block used in Experiment 3; lump of metal used in Experiment 4; spring balance or other balance; linen thread.

Introductory:

Iron is heavier than wood and lead is heavier than iron. By this we mean that, if we take pieces of the three materials of the same size, the lead has the greatest weight, and so we conclude there are more pounds per cubic foot (or grams per cubic centimeter) of lead than of iron or of wood. That is, the lead has the greatest *density*, for density is the mass per unit volume of a substance. In the metric system this is written grams per cubic centimeter or $\frac{\text{g.}}{\text{cm.}^3}$.

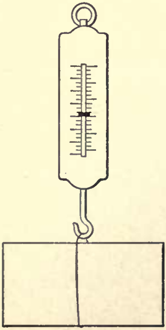

Fig. 8.

Experimental:

All that is necessary for the calculations is to know the mass and volume. The volume of each of the solids to be used has already been obtained in Experiments 3 and 4.

The mass of a body is measured by its weight. The greater the mass, the more a body will stretch a spring from which it is hung. The graduations on the scale of the spring balance indicate the masses that must be hung upon the hook, in order to pull the pointer

to each division on the scale. The mass of the block may be found, then, by hanging it upon a spring balance. Read the balance to tenths of the smallest division.

If a beam or a platform balance is used, read on page 11 or on page 9 the directions for its use before performing this experiment.

Observations

Mass of wood	*g.*
Mass of metal	*g.*

From your apparatus make, on the left-hand page of the note-book, an outline drawing like Fig. 8. On the same page write a simple description of what you did.

Make the calculations and put the results in a table at the top of the right-hand page of the note-book.

Calculated Results

Volume of block (from Exp. 3)	*cm.*^{3}
Volume of metal (from Exp. 4)	*cm.*^{3}
Density of wood	*g. per cm.*^{3}
Density of metal (_____)	*g. per cm.*^{3}

Conclusion:

The density of wood is _____

The density of _____ (name metal) is _____

EXPERIMENT 6

Elasticity — Hooke's Law

OBJECT. To find the relation between the elongation of a spiral spring and the stretching force, provided the elastic limit is not exceeded.

APPARATUS. A closely coiled spiral about 10 cm. long and 1.7 cm. in diameter, made of #20 spring brass wire, with a hook and pointer at one end and at the other a straight section for hanging or clamping; stand with pendulum clamp and meter stick clamp; meter stick; pan for suspension; metric weights.[1]

Introductory:

When a steamboat makes its landing, the large hawsers tighten as the boat is swung toward the wharf. The diameter of the large rope becomes smaller and measurements would show the length had been stretched. The stretching force has changed both the shape and volume of the rope. When the the line is cast off again, the rope, because it is an elastic body, recovers very nearly its original diameter and length. Sometimes the stretching force is so great that the rope snaps because the ultimate strength of the rope has been exceeded.

In materials subjected to stretching forces, as the wire in the coil of a spring balance, the change in diameter is very slight, but there is considerable lengthening or *elongation*. The question arises whether the elongation proceeds irregularly or at a uniform rate as the stretching force increases, provided the elastic limit of the material is not exceeded.

[1] The spiral coil may be conveniently made by winding the wire around a $\frac{1}{2}''$ pipe. The special pendulum and meter stick clamps may be replaced with ordinary laboratory clamps or other attachments. In case weights heavier than those specified for the loads are used, a larger size of wire should be selected.

Experimental:

Place the meter stick in a vertical position. Suspend the weight pan on the hook of the spring and attach the pointer just above the hook at right angles to the spring. Suspend the spring so that the end of the pointer is close to the metric scale, but does not touch it. Also try to adjust the position of the spring so that the pointer is opposite some main division of the metric scale such as the 10-cm. or 20-cm. mark. This mark is the zero reading or the point from which the first elongation is to be measured. Record this zero reading.

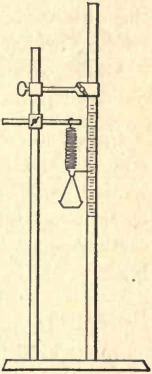

Fig. 9.

Put a 5-gram weight in the pan and read the position of the pointer. Take off this weight and allow the spring to go back. Again read the position of the pointer. Now put on the 10-gram weight. Continue in

OBSERVATIONS

LOAD ON PAN	READING OF POINTER	ZERO READING	CORRECTED READING (TOTAL ELONGATION)
5 grams	cm.	cm.	cm.
10 grams	cm.	cm.	cm.
15 grams	cm.	cm.	cm.
20 grams	cm.	cm.	cm.
25 grams	cm.	cm.	cm.
30 grams	cm.	cm.	cm.
35 grams	cm.	cm.	cm.
40 grams	cm.	cm.	cm.
45 grams	cm.	cm.	cm.
50 grams	cm.	cm.	cm.
55 grams	cm.	cm.	cm.
60 grams	cm.	cm.	cm.

this manner, increasing the load 5 grams at a time and recording the results in tabular form near the top of the left-hand page. The total elongation due to the load is the difference between the pointer reading and the zero reading which is made each time.

Make a drawing from your apparatus, and write a simple description of the experimental method.

Curve on Cross Section Paper. With the loads taken and the total elongations obtained, plot a curve on cross section paper, placing loads on the perpendicular axis and total elongations on the horizontal axis. Attach the cross section paper by one edge to the right-hand page of notebook.

Discussion:

What kind of a curve is obtained? What relation does this show between the total elongation and the stretching force? How elastic should the spring be in order to obtain very exact results? Was your spring such a spring? What is the principle upon which a spring balance works?

Conclusion:

Complete the following statement of Hooke's Law: When the elastic limit is not exceeded, the distortion of a body due to a stretching force is . . . . . . to the . . . . . . force.

EXPERIMENT 7

Tenacity of Wire

OBJECT. To determine (*a*) the relation between the tension and the elongation of a wire; (*b*) the comparative tenacity of copper, iron, and brass.

APPARATUS. Block for clamping wire; pulley with stem; thumb tacks; weight carrier; slotted weights — 1 lb., 2 lb., 2 lb., 5 lb., 10 lb.; millimeter scale; large-sized needle; magnifier (a cheap convex lens may be used).

MATERIAL. Spools of iron, brass, and copper wire, # 28; sealing wax.

Introductory:

When a load is suspended by means of a cord, the cord stretches. As the suspended weight is increased, the cord stretches further until it finally breaks. A wire or a metal rod behaves in the same way, but the elongation is smaller and not so readily noticed. There is, however, definite elongation. This must be allowed for in the construction of bridges and other structures. By experimenting with fine wire under increasing loads, we can follow all the changes until the wire breaks.

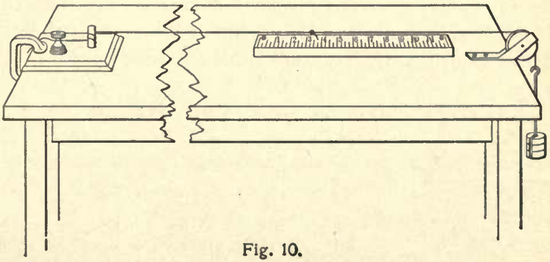

Fig. 10.

Experimental:

(*a*) The block is clamped to one end of the laboratory table and the stem of the pulley set into a hole bored diagonally into the opposite end.

A piece of wire about 30 cm. longer than the table is cut off. This is clamped to the binding post, given a turn around the wooden cylinder, and attached to the weight carrier at the other end. Care must be taken that there are no kinks or sharp bends anywhere in the wire. The wire is then placed over the pulley and the needle attached at right angles to it with a drop of melted wax at a point near the pulley.

The millimeter scale is then fixed in place beneath the the needle with the thumb tacks so that its divisions are parallel to the needle.

A 2-lb. weight is next placed on the carrier to straighten the wire; then it is removed and the zero reading of the needle taken, tenths of the smallest scale division being estimated. A lens may be used to advantage in estimating tenths.

Weights are now added, a pound at a time, the amount of stretching force and the reading of the needle on the scale being noted and immediately recorded in tabular form near the top of the left-hand page.

After each reading remove the weights and again note the zero reading. The force which causes the first considerable shifting in the zero point is known as the *elastic limit.* Continue the readings until the wire breaks.

OBSERVATIONS ON —— WIRE, GAUGE NO.

STRETCHING FORCE	ZERO READING	READING OF POINTER	BREAKING STRENGTH
----	----	----	----
----	----	----	----
etc.	etc.	etc.	etc.

(*b*) Replace the broken wire with another of different material, and add the weights one pound at a time until the wire breaks, without recording the elongations. Repeat with as many wires as the instructor may designate. Record results in tabular form on the second left-hand page.

OBSERVATIONS, PART (*b*)

MATERIAL OF WIRE	GAUGE NUMBER	BREAKING STRENGTH
----	----	-----
----	-----	----

On the left-hand page of the note-book make a simple drawing of your apparatus, and write a simple description of how the experiment was done.

On the right-hand page, at the top, place the calculated results for Part (*a*) in tabular form.

CALCULATED RESULTS

Stretching force	1 *lb.*	2 *lb.*	3 *lb.*,	*etc.*
Elongation	----- *mm.*	------ *mm.*	----- *mm.*, *etc.*	

Curve. — On a piece of cross section paper, plot a curve, laying off forces as abscissæ (horizontal) and elongations as ordinates (vertical) to the scale given by the instructor. *Compare the force at the point where the curve begins to turn with the elastic limit.* Paste the cross section paper by one edge into the note-book.

Discussion:

Does the wire follow Hooke's Law in that "the distortion (elongation) is proportional to the stretching force," through any part of the test as shown by the curve? If so, up to what point?

Conclusion:

(1) State the relation between the tension of a wire and its elongation (*a*) up to the elastic limit, (*b*) beyond the elastic limit.

(2) Arrange the materials tested in the order of their tensile strength, placing the strongest first.

EXPERIMENT 8

Relation between Pressure and Depth

OBJECT. — To find the relation between the depth of a submerged surface and the pressure upon it.

APPARATUS.[1] A test tube loaded with shot, upon which melted paraffin has been poured, so that the tube will float vertically; a paper centimeter scale, attached vertically to the inside of the tube with paraffin; weights — 1 to 10 grams if a $6'' \times \frac{3}{4}''$ test tube is used and 5 to 20 grams if a $8'' \times 1''$ test tube is used; battery jar or hydrometer jar; cross section paper.

Introductory:

When a stick is thrown endwise into water, it springs back into the air. When a boat floats in water, there must be an upward pressure of the water on it to balance its weight. When more heavily loaded, it sinks more deeply, but the upward pressure must then also balance its weight.

Experimental:

A glass tube loaded so that it will remain upright will be floated in a jar of water. A scale on the inside of the tube will be used to measure changes in depth. This

[1] **The method of this experiment was called to our attention by Dr. H. C. Cheston of the High School of Commerce, New York City.**

tube should float freely and should not be allowed to touch the sides of the jar. The scale readings are taken by sighting through the jar along the under side of the water surface. By adding small weights as indicated in the table below, the level of the bottom of the tube may be changed. By comparing the changes in depth and the changees in weight producing them, we may find how the upward pressure of the water (which balances the weight of the tube) varies with the depth of the surface on which it acts.

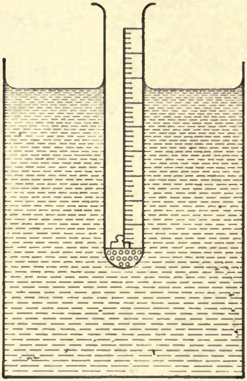

Fig. 11.

Place your observations in a table near the top of the left-hand page.

OBSERVATIONS

Number of Observation	Weight	Scale Reading
1	*Loaded tube alone*	*cm.*
2	*Loaded tube alone* + 2 *grams* . .	*cm.*
3	*Loaded tube alone* + 4 *grams* . .	*cm.*
4	*Loaded tube alone* + 6 *grams* . .	*cm.*
5	*Loaded tube alone* + 8 *grams* . .	*cm.*
6	*Loaded tube alone* + 10 *grams* . .	*cm.*

Make a drawing from your apparatus and write a simple description of the method of the experiment.

Make the following tabulations at the top of the right-hand page:

Calculated Results

Numbers		Change of Pressure		Change of Depth
1 — 2	. . . . .	*grams*	. . . .	*cm.*
1 — 3	. . . . .	*grams*	. . . .	*cm.*
1 — 4	. . . . .	*grams*	. . . .	*cm.*
1 — 5	. . . . .	*grams*	. . . .	*cm.*
1 — 6	. . . . .	*grams*	. . . .	*cm.*

Curve on Cross Section Paper. — The readings of change of pressure and change of depth should be plotted on cross section paper, depths on the perpendicular axis and pressures on the horizontal axis. Use a scale of 5 small spaces to 1 gram, and 2 small spaces to 1 mm. If the resulting graph is a straight line, we may conclude that twice the depth was caused by twice the pressure and so on, or that the pressure is directly proportional to the depth. Paste the cross section paper by one edge in the note-book.

Discussion:

At each observation in the experiment, what relation must exist between the total weight of the floating tube and the upward pressure of the water? Why is it not necessary to consider any sidewise pressures that may be exerted on the tube?

Conclusion:

What is the relation between the pressure on a submerged surface and the distance of that surface below the surface of the liquid?

EXPERIMENT 9

Archimedes' Principle

OBJECT. To determine the relation between the loss of weight of a sinking solid and the weight of a liquid displaced by it.

APPARATUS. Lump of coal with thread, or copper wire #22 attached; overflow can; catch bucket or beaker with wire loop for suspension; spring balance (250 g.), or beam balance; battery jar.

Introductory:

It is much easier to lift the anchor of a boat when the anchor is in the water than when it is out of the water. The displaced water balances part of the weight of the anchor, and so makes it seem lighter, because the upward pressure of the water on the bottom of the anchor is greater than the downward pressure on the top. The anchor displaces a volume of water its own size. We wish to compare the loss of weight of a body submerged in a liquid with the weight of the liquid displaced by it. This was first done by Archimedes, and the relation found is called *Archimedes' Principle.*

Experimental:

Use a piece of coal for the solid. By weighing it *in air*, with a spring balance, and then when *immersed in water* in a jar, the loss in weight of the lump can be found.

When a can with a spout, called an overflow can, is filled and placed on a level table, the water will run out to the level of the spout. By placing a weighed beaker under the spout and carefully lowering the coal into the can, the water which overflows may be caught and weighed. Comparing the weight of this displaced water with the loss of weight of the coal, will give the relation sought.

Record the following readings in tabular form near the top of the left-hand page:

Observations

Weight of coal in air . . . . *g.*
Weight of coal in water . . . . *g.*
Weight of catch bucket . . . . *g.*
Weight of catch bucket + displaced water . . *g.*

Briefly describe what you did, illustrating each step with a drawing from your apparatus, similar to Fig. 12 (*A*, *B*, and *C*).

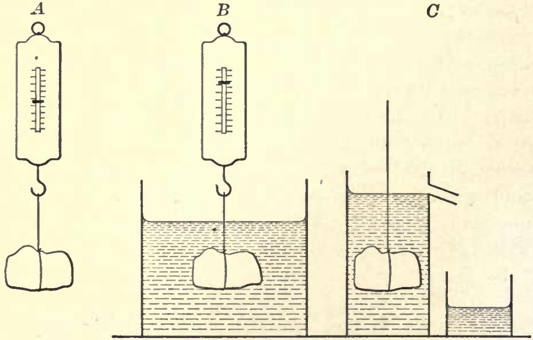

Fig. 12.

Calculated Results

Loss of weight of coal in water . . . . *g.*
Weight of an equal volume of water . . . . . *g.*

Conclusion:

State the relation between the loss of weight of a sinking body and the weight of a liquid displaced by it.

EXPERIMENT 10

Law of Flotation

OBJECT. — To determine the relation between the weight of a floating body and the weight of a liquid displaced by it.

APPARATUS. Block loaded to float upright on water; overflow can; catch bucket or beaker with wire loop for suspension; spring or beam balance.

Introductory:

The cork float on a fishline exerts no pull on the line. The weight of an ocean liner is supported by the upward push of the water. A boat is said to have a certain number of tons displacement, depending upon its size and weight. What is the relation between this number of tons of water displaced and the weight of the boat?

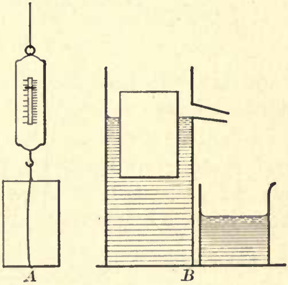

Fig. 13.

Experimental:

A method similar to that used in Experiment 9 will give us the relation between the weight of the wooden block and the weight of the liquid displaced by it. Place the table of observations near the top of the left-hand page.

OBSERVATIONS

Weight of block	*g.*
Weight of catch bucket, empty	*g.*
Weight of catch bucket + displaced water . .	*g.*

Write a simple description of the steps in the experiment, illustrating each with a drawing from your apparatus.

Place the table of calculated results at the top of the right-hand page.

CALCULATED RESULTS

Weight of water displaced by floating body . .		*g.*
Comparison of weights	*floating body*	*g.*
	displaced water . . .	*g.*

Conclusion:

The weight of a floating body and the weight of the liquid displaced by it are ——.

EXPERIMENT 10 (Alternative)

Law of Flotation

OBJECT. To determine the relation between the weight of a floating body and the weight of the liquid displaced by it.

APPARATUS. A wooden bar 20 cm. long and 1 cm. square with metric scale attached and loaded so as to be *almost* submerged when floating upright in water;[1] hydrometer jar or battery jar; platform balance; metric weights.

Introductory:

The cork float on a fishline exerts no pull on the line. The weight of an ocean liner is supported by the upward push of the water. A boat is said to have a certain number of tons displacement, depending upon its size and

[1] The ordinary wooden hydrometer can be made available by drilling a hole in the lower end, adding lead shot, and closing with a cork plug. The weight of the bar should be so adjusted that the bar will float *almost* submerged. Finally put a light coat of paraffin over the end which was opened.

weight. What is the relation between this number of tons of water displaced and the weight of the boat?

Experimental:

The wooden bar is to be weighed and then floated in the water of jar so as to note the depth to which it is submerged. The metric scale on the bar gives the length of the column of water displaced and, like the bar the column of displaced water, is 1 centimeter square. Therefore the reading on the metric scale is numerically equal to the number of cubic centimeters of displaced water. Since a cubic centimeter of water at ordinary temperatures weighs approximately a gram, the weight of the displaced water can easily be found. A comparison of the weight of the floating bar and the weight of the displaced water will bring out the principle of flotation.

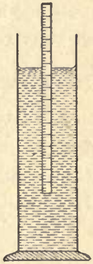
Fig. 14.

Observations

Weight of bar	*g.*
Length of column of displaced water . . .	*cm.*

Make a drawing of the floating bar from your apparatus and write a simple description of the experimental method.

Calculated Results

Volume of water displaced by floating body .		*cm.*^{3}
Weight of water displaced by floating body .		*g.*
Comparison of weights	*floating body* . .	*g.*
	displaced water . .	*g.*

Conclusion:

The weight of a floating body and the weight of the liquid displaced by it are ——.

EXPERIMENT 11

Specific Gravity of Solids

OBJECT. To find the specific gravity of various solids.

APPARATUS. Spring balance, or beam balance arranged for weighing in water; battery jar; pieces of coal, glass, and marble, or other solids desired.

Introductory:

Lead is a very heavy metal. While a pailful of water weighs only about 20 pounds, the weight in pieces of lead that would just fill the pail would be about 225 pounds. Lead weighs about 11.2 times as much as the same volume of water. We say that the "specific gravity" of lead is 11.2 times. The *specific gravity* of a substance is the *number of times* a piece of the substance is as heavy as the same volume of water.

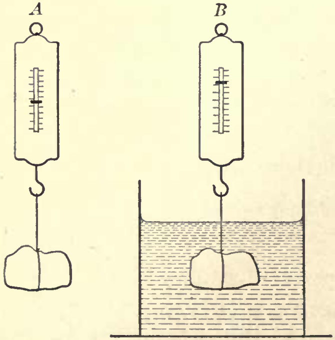

Fig. 15.

Experimental:

It will be necessary to get the weight of a lump of coal and the weight of the same volume of water. The weight of the coal can be found directly with a spring balance, and Archimedes' Principle will help us in getting the weight of an equal volume of water. If the coal is weighed while immersed in water, it will weigh less than

in air by an amount equal to the weight of water having the same size (volume) as the coal. The specific gravity of the other solids furnished may be found in the same way.

Record the weighings in tabular form near the top of the left-hand page.

OBSERVATIONS

	COAL	MARBLE	GLASS
Weight of body in air . .			
Weight of body in water .			

Then make drawings from your apparatus and write a simple description of how the experiment was done.

Place the table of calculated results at the top of the right-hand page.

CALCULATED RESULTS

	COAL	MARBLE	GLASS
Weight of water size of solid .			
Weight of solid			
Specific gravity of solid . .			

Conclusion:

The specific gravity of coal is ----- times; the specific gravity of marble is ----- times; the specific gravity of glass is ----- times.

EXPERIMENT 12

Specific Gravity of a Liquid

(Bottle Method)

OBJECT. To obtain the specific gravity of a solution of copper sulphate with a specific gravity bottle.

APPARATUS. Specific gravity bottle; spring balance (250 g.) with scale pan, or beam balance; bottle or jar of copper sulphate solution provided with a siphon delivery tube, ending with rubber connection, pinchcock, and glass jet tube (Fig. 17).

MATERIAL. Water; saturated solution of copper sulphate;[1] small cloths for wiping.

Introductory:

If we find the weight of a gallon of water and of a gallon of alcohol, we can directly determine the specific gravity of the alcohol by finding how many times it is as heavy as water. This is a general method for finding the specific gravity of any liquid.

Fig. 16.

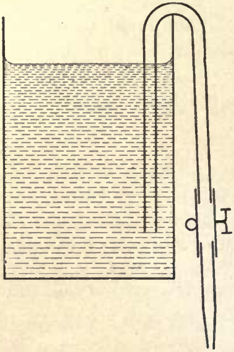

Fig. 17. Jar and siphon for solution.

Experimental:

We use small specific gravity bottles having perforated glass stoppers, as in this way we can

[1] A hot saturated solution should be made and allowed to cool, or a cheesecloth bag full of copper sulphate crystals should be suspended in the top of a jar of water and allowed to stand at least twenty-four hours, or until no more copper sulphate will dissolve.

obtain very exactly equal volumes of the two liquids. The weight of the specific gravity bottle must first be found. Then it is to be weighed full of water and next full of copper sulphate solution. By comparing the weight of the copper sulphate solution filling the bottle with the weight of the water filling the same space, the specific gravity of the copper sulphate solution may be found.

CAUTION. Using the wiping cloths if necessary, see that the bottle is dry on the outside before weighing and avoid handling it except by the neck, for the heat of the hand is likely to drive out some of the liquid through the stopper, after it has been fitted. After the water weighed has been emptied out, rinse the bottle with a little of the sulphate solution.

Record the weighings in tabular form near the top of the left-hand page.

Observations

Weight of scale pan and empty bottle	*g.*
Weight of pan and bottle filled with water . .	*g.*
Weight of pan and bottle filled with copper sulphate solution	*g.*

Make drawings from your apparatus and write a short description of how the experiment was done.

Place the table of calculated results at the top of the right-hand page.

Calculated Results

Weight of water filling bottle	*g.*
Weight of copper sulphate solution filling bottle .	*g.*
Specific gravity of copper sulphate solution . .	*times*

Conclusion:

The specific gravity of copper sulphate solution is ---- times.

EXPERIMENT 13

Specific Gravity of a Liquid

(Hydrometer Method)

OBJECT. To find the specific gravity of a copper sulphate solution by the hydrometer method.

APPARATUS. Hydrometer jars; square wooden hydrometer graduated in millimeters; glass hydrometer for heavy liquids (1 to 2).

MATERIAL. Water; saturated solution of copper sulphate as in Experiment 12.

Introductory:

A boat, passing from fresh water into the ocean, rises a little, as the boat displaces its own weight in each case, and the salt water, being more dense, has less volume for the same weight. An electric light bulb in concentrated sulphuric acid floated with 100 c.c. of its volume submerged; in alcohol, which is half as dense as sulphuric acid, the same bulb would sink until 200 c.c. were submerged. We see, then, that the greater the specific gravity of a liquid the less portion of a given floating body will be submerged in it. More exactly, the volumes of a floating body submerged in two liquids are inversely proportional to the specific gravities of the two liquids.

Experimental:

(*a*) A graduated float used for obtaining the specific gravity of liquids is called an ***hydrometer***. The hydrometer to be used is a loaded stick 1 cm. square and graduated in centimeters and tenths. If we now immerse this in water (Fig. 18) and record the depth to which it sinks, and then do the same with a copper sulphate solution

(Fig. 19), the hydrometer will sink deeper in the less dense liquid. The volume of each liquid displaced may be measured by the depth of the submerged part of the hydrometer, since each centimeter of length means 1 c.c. of volume. If, then, we divide the length submerged in in water by the length submerged in copper sulphate, we shall obtain the specific gravity of the copper sulphate solution.

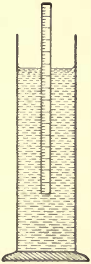

Fig. 18.

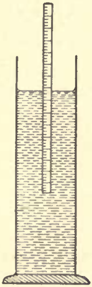

Fig. 19.

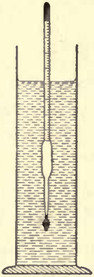

Fig. 20.

(*b*) Direct-reading hydrometers are made of glass tubes loaded so as to float upright and provided with a scale which gives the specific gravity directly (Fig. 20). After completing calculations on part (*a*), ask the instructor for such a hydrometer, and with it find the specific gravity of your solution, as a check on your results. Record the observations in tabular form near the top of the left-hand page.

Observations

Reading of bar in water . . . . *cm.*

Reading of bar in copper sulphate solution . *cm.*

Reading of glass hydrometer in copper sulphate solution . . . .

Make drawings from your apparatus showing the posi tion of the wooden hydrometer in the two liquids and the position of the glass hydrometer in the copper sulphate solution. Accompany these drawings with a short description of the method of work.

Calculated Result

Specific gravity of copper sulphate solution as determined by wooden hydrometer . . times

Discussion:

Explain why the volume of water displaced was divided by the volume of copper sulphate solution displaced.

Conclusion:

The specific gravity of the copper sulphate solution
by this method (wooden hydrometer) is ----- times
by the bottle method (Experiment 12) is ----- times
by the direct reading of the glass hydrometer is ----- times

EXPERIMENT 14

Specific Gravity of a Liquid

(Hare's Method)

OBJECT. To find the specific gravity of alcohol and of a salt solution by Hare's method.

APPARATUS. Two 90 cm. lengths of $\frac{1}{4}''$ glass tubing; lead or glass T-tube, or Y-tube; 2 rubber connections; black rubber tubing of length convenient for suction; screw compressor; ring stand and clamp for supporting T-tube or Y-tube; 2 tumblers (preferably of thin glass and with nearly vertical sides), or 2 beakers.

MATERIAL. Distilled water, if available; saturated solution of common salt, and grain alcohol in stock bottles provided with siphon tubes about $\frac{5}{16}''$ bore.

Introductory:

The simple barometer is nothing more than a long tube, closed at one end and filled with mercury, which is then inverted in a dish of mercury. A mercury column about 76 centimeters in length remains standing in the tube. This column is held up by the pressure of the atmosphere. It has also been determined experimentally that the pressure of the air supports a much longer column of water — approximately 34 feet. We know that mercury, volume for volume, is much heavier than water, or, as we say, has a greater specific gravity. The fact that the atmosphere holds up columns of liquid whose length varies with the particular liquid taken, has been utilized in an ingenious method for determining the specific gravity of liquids.

Experimental:

The apparatus (Fig. 21) consists of two long parallel tubes with their lower ends dipping into tumblers of liquids. The upper end of each is joined by a rubber connection to an arm of a T-tube. To the center tube of the T is attached a rubber tube to be used for suction, which can be closed by a screw compressor.

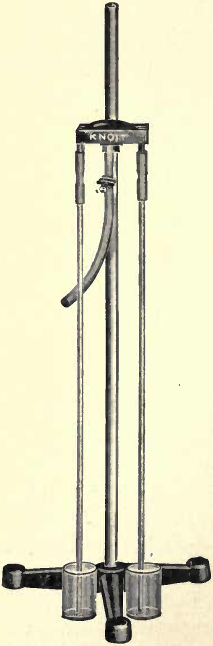

Fig. 21.

(*a*) Half-fill one tumbler with water and the other with a saturated solution of salt.

With the rubber tubing open, compare the water levels inside and outside the long tube. *Account for this condition of levels.* Is it also true for the levels of the salt solution?

Suck out a little air through the rubber tube, noting the behavior of the liquids. *What pressure causes the liquids to rise in the tubes?*

Again remove air by suction until the water column is pushed up nearly to the top of its tube. Pinch the rubber tube tightly and close the screw compressor. Note the relative height of the two liquids. The pressure on the upper surfaces of the two liquids is the same. *How does this pressure compare with the outside air pressure? What pressure forced the liquids*

up into the tubes? How does this pressure compare with the downward pressure of each liquid? Compare, then, the downward pressure of the water column with that of the salt solution.

Measure with a meter stick the length of the water column above the level of the water in the tumbler. Obtain similarly the length of the column of the salt solution. Record the measurements in tabular form near the top of the left-hand page.

(*b*) Open the compressor and allow the liquids to run back into their tumblers. Return the salt solution to its stock bottle and rinse out the tumbler. Detach the long tube used for the salt solution, and, after washing, attach it again.

Put grain alcohol into the empty tumbler and repeat the experiment so as to obtain the length of the water and the alcohol columns, *taking care not to suck the alcohol up into the mouth.* Tabulate the measurements near the top of the left-hand page.

Return the alcohol to its stock bottle.

Observations

Part (a):

Length of the water column . . . . *cm.*
Length of the salt solution column . . . . *cm.*

Part (b):

Length of the water column . . . . *cm.*
Length of the grain alcohol column . . . . *cm.*

Make an outline drawing of the apparatus used, and write a simple description of the general method of the experiment.

With the water and the salt solution, the downward pressure per square centimeter of each, balances the same amount of atmospheric pressure. The two columns must

then have the same weight. Being of equal cross section, their lengths are proportional to their volumes. But the greater the specific gravity of a liquid, the smaller the volume for a given weight. *Are the relative weights, then, directly or inversely proportional to the heights of the columns?* With this relation in mind, calculate the specific gravity of the salt solution and of the alcohol, relative to water. Record the results in tabular form at the top of the right-hand page.

Calculated Results

Specific gravity of the salt solution . . —— = *times*

Specific gravity of the alcohol . . . . . —— = *times*

Discussion:

Answer under this heading on the right-hand page the italicized questions occurring in the directions.

Conclusion:

The specific gravity of the salt solution is ----- times; the specific gravity of the alcohol is ----- times.

EXPERIMENT 14 (Alternative)

Specific Gravity of Liquids

(Balancing Columns)

OBJECT. To find the specific gravity of (*a*) carbon tetrachloride, (*b*) grain alcohol, by the method of balancing columns in a U-tube.

APPARATUS. 2 Mohr burettes (50 c.c.) connected by a piece of thick-walled rubber tubing of sufficient length; Hofmann screw compressor; ring stand; two burette clamps; 2 glass funnels, $2\frac{1}{2}''$, or tops of two thistle tubes; beaker; medicine dropper.

MATERIALS. Mercury; distilled water if available; carbon tetrachloride; grain alcohol. (Other liquids, such as glycerine kerosene, etc., as the instructor desires.)

Introductory:

When mercury fills the lower rounded portion of a U-tube, the mercury stands at the same level in the two arms, since the downward pressure of the air is the same on the two mercury surfaces.

When a certain volume of water is poured into one arm of this same tube, and an *equal* volume of kerosene into the other arm, the mercury level in the water arm is lower than that in the kerosene arm. Since the mercury is free to move, the given volume of water must press down with greater weight on the mercury than does the same volume of kerosene. Accordingly, volume for volume, the kerosene weighs less than the water. Usually the specific gravity is found by calculating the ratio between weights of equal volumes. Since this is so, might not the *inverse* ratio between the volumes of equal weights give the specific gravity?

Experimental:

As we have seen, equal weights may be measured by the downward pressure of liquids. The equal weights can be obtained by pouring just enough of each liquid into its arm of the U-tube, so as to make the two mercury surfaces stand at the same level. All that remains is the measurement of the volumes of the two liquids and the finding of the ratio, remembering that it is an inverse one.

Clamp the two burettes at about a third of their length from their lower ends and in a vertical parallel position with the 50-c.c. marks horizontally opposite each other.

Slip the screw compressor over the rubber connecting tube and attach the ends of the tube to the burettes.

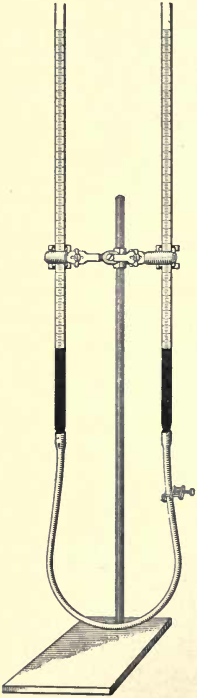

Fig. 22.

Pour mercury through a thistle tube top or funnel at the top of one burette until the mercury surface in each burette stands at the 50-c.c. graduation, or some mark a short distance above (Fig. 22). Squeeze out the air bubbles in the connecting tube before taking the zero reading of the mercury levels.

(*a*) Record the zero reading of the burettes in the table of observations. Then close the screw compressor on the connecting tube.

Into the right-hand burette pour enough carbon tetrachloride to half fill the burette. Add about the same volume of water to the other burette. Cautiously open the compressor a little, noting whether the tetrachloride column is balanced by the water. If not, close the compressor, add more water, and test again. Continue in this manner until the water balances the tetrachloride, as shown by the mercury remaining at the same levels when the compressor is opened wide. A medicine dropper is convenient for adding the last portions of water needed.

Read and record the top levels of the balancing columns.

Raise the tetrachloride burette so that the mercury just runs into the connecting tube. Over this end of the tube

close the screw compressor and slip off the rubber tube, so that the tetrachloride can empty into a beaker placed below the burette. Pour the tetrachloride into its stock bottle.

(*b*) Rinse out the open burette with a few cubic centimeters of alcohol (or other liquid to be used) and again connect the rubber tube.

Then obtain as in (*a*) a column of alcohol which balances the water column in the left-hand burette.

Record all readings in a tabular form near the top of the left-hand page.

Observations

Part (a):

Reading of mercury levels . . . . *cm.*^{3}
Reading at top of water column . . . . . . *cm.*^{3}
Reading at top of tetrachloride column . . . *cm.*^{3}

Part (b):

Reading of mercury levels . . . . *cm.*^{3}
Reading at top of water column . . . . . . *cm.*^{3}
Reading at top of alcohol column . . . . . *cm.*^{3}

Make an outline drawing of your apparatus and describe briefly how the experiment was done.

Place the table of calculated results at the top of the right-hand page. The specific gravities are to be calculated with reference to water.

Calculated Results

Part (a):

Volume of the water column . . . . . . *cm.*^{3}
Volume of tetrachloride column . . . . . *cm.*^{3}
Specific gravity of tetrachloride . . —— = *times*

Part (b):

Volume of water column . . . . *cm.*^{3}
Volume of alcohol column . . . . *cm.*^{3}
Specific gravity of alcohol . . . . —— = *times*

Discussion:

Why is the specific gravity in this experiment the *inverse* ratio of the volumes of the balancing columns?

Conclusion:

The specific gravity of carbon tetrachloride is ---- times. The specific gravity of alcohol is ----- times.

EXPERIMENT 15

Density of Air

OBJECT. To determine the approximate density of air in the room.

APPARATUS: Air pump; round-bottom flask (250 c.c.) with a tightly fitting 1-hole rubber stopper carrying a glass inlet tube with a piece of thick-walled rubber tubing attached; screw compressor; beam or horn pan balance weighing to 0.01 gram; metric weights; graduate; large battery jar, or pail.

Introductory:

It is very evident that lead has weight. Even a small child knows that a tumbler of water is heavier than the empty glass. We know that solids and liquids have weight, but does the air which surrounds us have weight? If balloons are lighter than air, the air must have weight. It would be interesting to find out just how dense air is, that is, the number of grams to a cubic centimeter.

Experimental:

A flask may be weighed full of air and then the air partially pumped out. Then the exhausted flask may be weighed. The difference between the two weights is the weight of air pumped out of the flask. The volume of

this air may be found by measuring the water which will run into the exhausted flask. With the weight and volume of the air known, the density (grams per cubic centimeter) may be found.

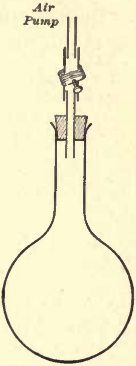

Fig. 23.

Make all weighings to the nearest centigram. In all weighings of the flask, include the rubber stopper with its tubing and screw compressor, and any wire suspension used with the balance. See that all joints between rubber and glass are tight before exhaustion. Allow at least five minutes for the exhaustion of the flask, and be sure the screw compressor is tightly closed before the removal of the rubber tube from the pump.

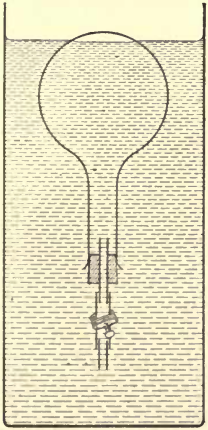

Fig. 24.

Immerse most of the flask in water and open the screw compressor a little at a time under water. As soon as no more water will run in, move the flask so that the level of the water on the inside is the same as that on the outside (Fig. 24).

Pinch the rubber tube with the compressor so as to close it, and remove the flask from the water. Set it in a secure upright position on the table. Open the compressor so as to allow the water in the small tube to run down into the flask and then remove the stopper and its connections.

Measure with a graduate the volume of water in the flask.

Record the measurements in tabular form near the top of the left-hand page.

Observations

Weight of flask filled with air	*g.*
Weight of flask, air exhausted	*g.*
Volume of air exhausted	*cm.*^{3}

Record, if so directed by the instructor, the temperature of the room and the barometric pressure.

Briefly describe the steps in the experiment, illustrating with drawings from your apparatus.

Place the table of calculated results at the top of the right-hand page.

Calculated Results

Weight of air exhausted	*g.*
Volume of air exhausted	*cm.*^{3}
Density of air	$\frac{\textit{grams}}{\textit{cm.}^3}$

Discussion:

After the water had run into the flask, the water levels were made the same, so that any air not pumped out of the flask would be at the same pressure as the air in the room. What is the necessity for this precaution? Would the results obtained for this experiment be exactly the same on different days? Give reasons for your answer.

Conclusion:

The density of the air in the laboratory at the existing conditions was ----- grams per cubic centimeter.

EXPERIMENT 15 (Alternative)

Density of Air

OBJECT. To determine the approximate density of air in the room.

APPARATUS. Incandescent lamp bulb; Bunsen burner; blowpipe; small battery jar; small funnel and graduate; horn pan balance weighing to 0.01 gram or better; metric weights; small squares of adhesive plaster.[1]

Introductory:

It is very evident that lead has weight. Even a small child knows that a tumbler of water is heavier than the empty glass. We know that solids and liquids have weight, but does the air which surrounds us have weight? If balloons are lighter than air, then air must have weight. It would be interesting to ascertain just how dense air is, that is, the number of grams to a cubic centimeter.

Experimental:

The bulb of an incandescent lamp is empty save for the filament and a very slight trace of gas which was not exhausted. The bulb then can be weighed empty. By making a small hole, the air will rush in and fill the bulb. Another weighing gives the weight of the bulb filled with air. The difference between the two weighings is the weight of the air in the bulb. The volume of this air may be found by filling the bulb with water and then measuring the water with a graduate. With the weight

[1] *Note to Instructor.* If the supply of burnt-out bulbs is limited, the experiment may be done in small squads, each student making the weighings and measurements for himself. In small classes the instructor may prefer to make the first air hole with the blowpipe.

and volume of the air known, the number of grams per cubic centimeter can be calculated.

Filling the Bulb with Air. — Use the tiny point of a blowpipe flame, but approach the portion to be heated very gradually with the flame so as to avoid the sudden cracking and collapsing of the bulb. Heat a small area near the top of the bulb where the diameter is greatest (Fig. 25). As the glass softens at the tip of the blowpipe flame, the pressure of the outside air will make a hole. Any bits of glass which may be chipped off will tend to be drawn inward so that there will be no loss of weight due to the glass. Only a tiny hole is needed to admit the air.

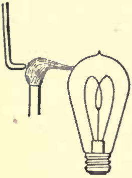

Fig. 25.

Filling the Bulb with Water. — After the bulb has been weighed full of air, heat it with the tip of a blowpipe flame so as to make a little hole in the glass an inch or so from the *base* of the lamp.

When the heated glass is cool, immerse the bulb upright in the water of a battery jar so as to leave the first air hole made just above the surface of the water (Fig. 26). When the bulb is nearly full, incline the bulb, so that the rest of the space can fill with water.

Then take the small square of adhesive plaster and stick over the lower hole, holding it in position for a couple of minutes with the finger. Now cover the *upper* air hole with the finger and remove the bulb from the water. Holding the bulb nearly upright over a funnel supported in a graduate, pierce through the adhesive plaster just over the lower air hole. When the finger over the

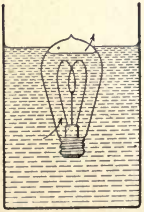

Fig. 26.

upper air hole is removed, the water will run down into the funnel. Remember that the outward flow may be stopped at any time by closing the upper hole with the finger.

Record the measurements in tabular form near the top of the left-hand page.

Observations

Weight of incandescent bulb empty	*g.*
Weight of bulb filled with air	*g.*
Volume of air filling bulb	*cm.*^{3}

Record, *if so directed*, the temperature of the air in the room and the barometric pressure.

Describe briefly the steps in the experiment and illustrate with drawings from your apparatus.

Place the table of calculated results at the top of the right-hand page.

Calculated Results

Weight of air filling bulb	*g.*
Volume of air filling bulb	*cm.*^{3}
Approximate density of air	$\frac{grams}{cm.^3}$

Conclusion:

The approximate density of air in room at existing conditions was ----- grams per cubic centimeter.

EXPERIMENT 16

Boyle's Law

OBJECT. To find how the volume of a gas varies with the pressure exerted upon it.

APPARATUS. Barometer; Boyle's Law apparatus as furnished by dealers in scientific instruments. The two forms recommended are: (1) the apparatus with the closed tube ending in glass stopcock, and the open tube connected with the closed tube by heavy-walled tubing; (2) the apparatus with both tubes dipping into a mercury reservoir, the closed tube sealed at the upper end, and a small bicycle pump to produce pressure in reservoir, so as to make mercury rise in the two tubes.[1]

MATERIAL. Mercury, if not supplied with the apparatus.

Introductory:

A bicycle pump takes in air and makes it occupy a much smaller space. We know that the air in the inflated tube is under much greater pressure than before. Oxygen is sold in steel cylinders filled under pressure. When the valve is opened, many jars of oxygen may be obtained from one tank for experiments in the chemical laboratory. The total volume of the jars filled is far greater than that of the cylinder, for the oxygen is under much less pressure in the jars than in the steel tank. The two instances of

[1] *Note to Instructor.* The directions for this experiment have been written so that either of the two forms of apparatus may be used. Both forms are on hand in many schools. A good type of the first apparatus may be obtained from the C. H. Stoelting Co., Chicago (list number 1151); the second form with an improved mercury reservoir is made by the L. E. Knott Apparatus Co., Boston (list number 41–105).

The authors regard the J-tube form as very desirable for demonstration purposes, but less fit for the laboratory experiment, as most students are unable to handle it without spilling the mercury required.

the inflated tire and the filling of jars with oxygen show that there is some relation between the volume of the gas and the pressure exerted on it. Whether or not there is any regularity in this relation, may be ascertained by experiment.

Experimental:

Specific directions for handling the apparatus will be given by the instructor.

The volume of air used is that inclosed above the mercury in the closed tube. The mercury in the open tube is used for varying the pressure upon the inclosed air. When the mercury levels are the same in the two tubes, the inclosed air is under atmospheric pressure. When the mercury level is higher in the open tube, then the inclosed air is under more than atmospheric pressure, for a column of mercury equal in height to the *difference in levels* is adding its pressure to the atmospheric pressure. A lower level in the open tube means a pressure less than the atmospheric.

The pressure is expressed in centimeters of mercury. If the bore of the closed tube is of uniform diameter, the length of the inclosed air column may be taken as the measure of its volume and recorded in centimeters.

Make a number of readings, as directed by the instructor. The difference of the mercury levels in the open tube between successive readings, should be about 10 cm. One reading should be made with the mercury at the same level in the two tubes.

As soon as the readings are made, record them in tabular form at the top of the left-hand page.

Write a simple description of the method of using the apparatus and make an outline drawing of it, showing the essential parts.

Observations

Number of Reading	Column of Inclosed Air		Mercury Level Open Tube
	Top	Bottom	
1	cm.	cm.	cm.
2	cm.	cm.	cm.
etc.			

Barometric pressure at---------(time)on---------(date)was----mm. = cm.

Place the calculated results in tabular form at the top of the right-hand page. The difference in the mercury levels can be found from the quantities in the last two columns of the table of observations.

The pressure of the inclosed air is atmospheric pressure *plus* or *minus* (as the case may be) the difference of mercury levels. In recording the product of the pressure by the volume, omit the decimal fractions.

Calculated Results

Number of Reading	Difference in Levels	Pressure of Inclosed Air	Volume of Inclosed Air	Pressure × Volume
1	cm.	cm.	$cm.^3$	
2	cm.	cm.	$cm.^3$	
etc.				

Discussion:

Is the product of the pressure and the volume approximately constant? Why should the temperature of the inclosed air not change while the readings are being made? Would a variation in the barometric pressure during the experiment affect the result?

Conclusion:

Complete the following statement:

At a constant temperature, the volume of a given mass of gas varies ----- as the pressure sustained by it.

EXPERIMENT 17

Measurement of Gas Pressure

OBJECT. To measure the pressure of the laboratory gas supply.

APPARATUS. Water manometer, consisting of a U-tube (8″) with one arm carrying a tightly fitting 1-hole rubber stopper with glass elbow tube;[1] block with slot or groove for supporting U-tube; foot rule or a metric scale; rubber tubing for connecting manometer with gas cock; barometer.

Introductory:

The bag of a balloon connected with a gas main, fills and rounds out as the gas rushes in. One can feel the gas pressing out when a stopcock is opened from the gas supply in the laboratory. The balloon fills and the gas rushes into the room despite the fact that the weight of the air is pressing around the bag of the balloon and against the opening of the gas cock. This pressure, which is effective against the atmospheric pressure, may be described as the effective pressure of the gas supply. How much is the effective pressure of the gas delivered to our homes and school?

Experimental:

Enough water is added to the U-tube to fill it about halfway up, and then the stopper carrying the elbow tube is pressed tightly into one arm of the tube. The water levels in the two arms are at the same height, since the air presses down on both water surfaces equally.

The elbow tube is connected by a rubber tubing with

[1] Instead of the U-tube, a U-shaped bend of glass tubing with the arms about 8″ long, may be used. A Skidmore stand is very convenient for supporting the U-tube.

the gas supply. The gas stopcock is slowly turned on and the difference in the height of the water levels measured. This measurement should be made as soon as the rising water level reaches its greatest height.

Observations

Atmospheric pressure (barometer reading) . . *in.*
Difference in height of water levels . . . . *in.*
Time when readings were made . . . . .

If the measurements were made in centimeters, change them to inches by multiplying by 0.3937.

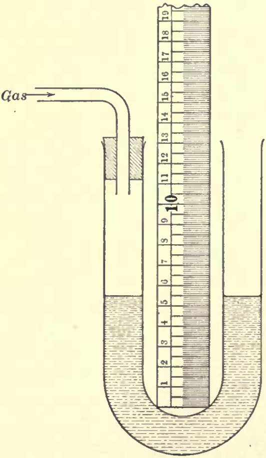

Fig. 27.

Write a simple description of the experiment and make a drawing showing how your apparatus indicated the gas pressure.

The difference of the water levels due to the increased pressure is independent of the cross section of the U-tube, therefore we can consider its cross section to be 1 square inch. A pressure of 14.7 pounds to the square inch holds up a water column 33.57 feet in length. From this equivalent, calculate the pressure in pounds per square inch of a column of water equal in height to the difference of levels measured in the U-tube. This will give the *effective* pressure of the gas.

A pressure of 14.7 pounds to the square inch holds up

a mercury column 30 inches in length. From this relation, calculate the pressure in pounds per square inch which is equivalent to the observed barometric reading.

Adding the effective pressure to the atmospheric pressure gives the *total* pressure of the gas, that is, the pressure per square inch within the gas pipes.

Record the calculated results in a table at the top of the right-hand page.

Calculated Results

Effective pressure of gas per sq. in.	*lb.*
Atmospheric pressure per sq. in.	*lb.*
Total pressure of gas per sq. in.	*lb.*

Discussion:

Why is it not necessary to remove the air in the arm of the U-tube connected with the gas supply? What is the gas pressure stated to be in your town or city? What does this mean?

Conclusion:

The effective pressure of the gas in the laboratory at ----- (time) on ----- (date) was ----- pound per square inch. The total pressure per square inch in the gas pipes was ----- pounds.

EXPERIMENT 18

Water Pumps

OBJECT. To study the parts and the operation of the simple lift pump and the force pump.

APPARATUS. Glass models of a lift pump and a force pump; 3 feet of glass tubing ($\frac{1}{4}''$) with a short piece of rubber tubing attached; battery jar.

Introductory:

The ordinary suction or lift pump has been used for over two thousand years. Although both the lift pump and the force pump are articles of familiar appearance, few can give an intelligent explanation of their operation. In these cases, as in other apparently simple devices, the study of the principles upon which they are based proves fascinating.

Experimental:

CAUTION. Handle the glass models with great care. Do not spill water around the laboratory.

(*a*) Place in a jar of water the lower end of a long glass tube which has a short rubber tube on the upper end. Compare the water levels in the tube and in the jar. Account for the relative levels.

Suck out through the rubber tube most of the air in the glass tube, noting the action of the water. Pinch tightly the upper end of the rubber tube. Does the water run back? *What pressure holds up the column of water in the glass tube?* Release the pressure on the rubber tube. What happens? *Explain. Why is it necessary to remove some of the air in a tube if we want water to be pressed up in it?*

Make three simple diagrams which will show what was done in this part of the experiment and indicate the results.

Fig. 28.

(*b*) *The Lift Pump.* — Examine a glass model of a lift pump, noting the suction tube, the barrel, the piston, the two valves, and the spout. Make an outline drawing, labeling the parts. Starting without any water in the pump, immerse the suction tube in a jar of water and operate the pump till it is in full action, noting the action of the *inclosed* air, the water, and the two valves on each successive stroke. Record the observations in tabular form on the left-hand page. *What is the main thing accomplished by the first few strokes of the pump?*

OBSERVATIONS ON THE LIFT PUMP

STROKE	VALVE	ACTION OF AIR	ACTION OF WATER	ACTION AND USE OF VALVE
1st Up	Lower			
1st Up	Upper			
1st Down	Lower			
1st Down	Upper			
2d Up	Lower			
2d Up	Upper			
etc.	etc.			

(*c*) By a rubber connection attach a long glass tube to the suction pipe of the lift pump. Dip the free end of the long tube into a jar of water placed on the laboratory floor. Can you pump water from the floor? *What limits the vertical distance through which water can be taken by a lift pump even though it were mechanically perfect?*

(*d*) *The Force Pump.* — Examine the glass model of a force pump, noting its parts. Try its action.

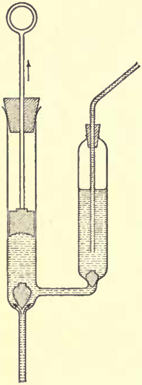

Fig. 29.

Make two diagrams showing the action of the pump — one for the up stroke, the other for the down. Show water levels, and use arrows to indicate the direction of water flow.

Will the force pump or the lift pump raise water to a higher level? *Why is this so?*

Do not write a description of the work done, as the drawings and tabulations show this. A few explanatory statements may be added if necessary.

Discussion:

Under this heading, on the right-hand page, answer the italicized questions in the experimental directions.

Is the action of these pumps due to pressure or to "suction." Which type of pump is a bicycle pump? Explain.

Why is a little water sometimes poured in at the top of a pump just before working the handle? (Class Discussion.)

EXPERIMENT 19

The Principle of Moments

OBJECT. When three parallel forces are in equilibrium, to compare (*a*) the forces in one direction with the force in the opposite direction; (*b*) the clockwise moments with the counterclockwise moments.

APPARATUS. Meter stick; loops of strong cord; 3 spring balances (2000 grams), with hooks for suspending them, or clamps for fastening the balances to the edge of the table top (Fig. 35).[1]

Introductory:

When a team of horses is drawing a wagon, their combined force forward is exerted to overcome the resistance of the wagon pulling backward. When two boys carry a heavy weight suspended from a stick, the boys pull upward and the weight pulls downward. If the boys have not equal strength, the weight will be shifted toward one of the boys. Which one?

In each of these cases, we have three forces parallel to each other, two in one direction and one in the opposite. These forces are in equilibrium when the stick is balanced. If one boy should lift more than he had been lifting, the stick would turn toward him. The turning effect of a force is called *the moment of the force.*

We can imitate either of these cases by attaching three spring balances to a meter stick, so that two pull in one direction and one in the other. We can then compare (*a*) the pull of the two forces in one direction with that

[1] This experiment can also be conveniently done by using two balances suspended vertically with a weight between, supported by a loop on the meter stick so that the weight may be moved to positions of equilibrium. If this modification is made, allowances must be made for the pull on the balances due to the weight of the meter stick.

of the single force in the other, and compare (*b*) the turning effect or moment of the force at one end with that of the force at the other end of the stick.

Experimental:

The apparatus will be arranged as shown in the diagram (Fig. 30). The amount of each force may be read on the balance. First each outside cord should be placed 10 cm. from its end of the meter stick and the third cord in the center. See that all cords are parallel. The highest reading on any balance should not be more than 1600 grams. When all is adjusted, the reading of each balance and the position of each string on the meter stick should be recorded (I).

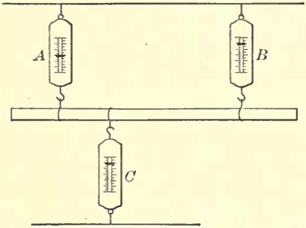

Fig. 30.

One end balance may then be shifted so that it is half as far from the center as the other. After adjustment, readings should again be taken (II). The total force in one direction may then be compared with the total force in the other, as indicated in the table for the right-hand page. The moment of a force is found by multiplying the force by its lever arm. The lever arm is the perpendicular distance from the fulcrum about which the force is trying to turn the body, to the force. In this experiment, the distance between each of the outer cords and the center cord will be the lever arm for the force applied by the cord, if the cords are at right angles to the meter stick. The moment of each of the end forces around the center cord is to be computed.

Record the readings in tabular form near the top of the left-hand page.

Observations

	I	II
Reading of balance A	-----	-----
Reading of balance B	-----	-----
Reading of balance C	-----	-----
Point of application of force A . . .	-----	-----
Point of application of force B . . .	-----	-----
Point of application of force C . . .	-----	-----

Make a drawing of your apparatus and write a simple description of how it was used. Place the table of calculated results at the top of the right-hand page.

Calculated Results

	I	II
Combined Force of A and B . . .	-----	-----
Force of C	-----	-----
Moment of A about C	-----	-----
Moment of B about C	-----	-----

Discussion:

Is the moment of *A* about *C* clockwise or counterclockwise? Is the moment of *B* about *C* clockwise or counterclockwise?

Conclusion:

Complete the following with a statement about the amount of force in each direction:

When three parallel forces act on the same body to produce equilibrium, then..

Complete the following by comparing with the moment of the third force around the second, both as to magnitude and direction:

When three parallel forces act on the same body to produce equilibrium, the moment of one of them about the second is..

EXPERIMENT 20

The Lever Arm of a Force

OBJECT. To determine the lever arms of non-parallel forces.

APPARATUS. Meter stick, with a hole on the center division near one edge, drilled slightly larger than the shank of a $\frac{3}{4}''$ screw eye; short piece of board about $\frac{7}{8}''$ stock; screw eye, $\frac{3}{4}''$; fish line; four clamps; half meter stick; draughtsman's triangle, 90°, 60°, and 30.°

Introductory:

In using such a lever as a crowbar, pump handle, or hammer, it is seldom that the forces exerted on and by the lever are parallel to one another. Under such circumstances, it would be desirable to know whether the lever arm is to be measured along the lever or at right angles to the applied force.

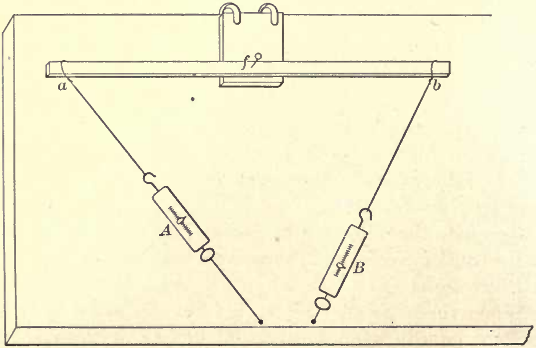

Fig. 31.

Experimental :

The meter stick is to be attached by the screw eye to a short board held firmly by two clamps to the edge of the laboratory table. The meter stick must be free to rotate around the shank of the screw eye as a fulcrum.

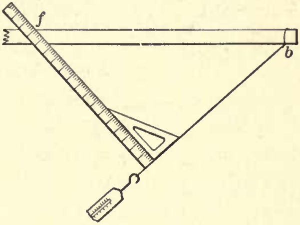

Fig. 32.

The hook of each balance is to be attached by a loop to the meter stick. The other end of each balance is to be clamped to the edge of the table opposite the meter stick. These two balances are to be clamped so that they make acute angles with the meter stick. One angle should be nearly a right angle and the other decidedly acute, as shown in Fig. 31.

Perpendicular distances may be measured by using a triangle and a half meter stick, as shown in Fig. 32.

Make the following readings and record in tabular form near the top of the left-hand page of note-book.

Observations

Reading of balance A	*g.*
Reading of balance B	*g.*
Point of application of force A	*cm.*
Point of application of force B	*cm.*
Position of fulcrum on meter stick	*cm.*
Perpendicular distance, fulcrum to force A .	*cm.*
Perpendicular distance, fulcrum to force B .	*cm.*

Make one drawing showing the arrangement of your apparatus and another drawing showing the method of

measuring the perpendicular distance of a force from the fulcrum. Write a simple description of how the experiment was done, referring to the drawings. Place the table of calculated results at the top of the right-hand page and make all the calculations on that page.

CALCULATED RESULTS

Distance along stick from fulcrum to a . . .	*cm.*
Distance along stick from fulcrum to b . . .	*cm.*
Force A × meter stick distance from fulcrum .	
Force B × meter stick distance from fulcrum .	
Force A × perpendicular distance from fulcrum	
Force B × perpendicular distance from fulcrum	

Discussion:

Which pair of products, in the table above, more nearly agrees with the principle of moments?

Conclusion:

How should the lever arm of a force always be measured?

EXPERIMENT 21

Composition of Several Parallel Forces

OBJECT. **When a number of parallel forces are in equilibrium, to compare (*a*) the total force in one direction with the total force in the opposite direction; (*b*) the clockwise moments with the counter-clockwise moments.**

APPARATUS. Meter stick; four or more spring balances (2000 g.), with cords and clamps.

Introductory:

A floor or bridge beam is frequently supported at more than two points and has a number of different persons or objects exerting their weights on it at various points. It is interesting to determine whether the principle of moments which has been tested for two forces acting about the point of application of a third as a fulcrum, will apply to this case also.

Experimental:

Four or more spring balances, as the instructor may direct, are to be attached by cords to a meter stick, as in

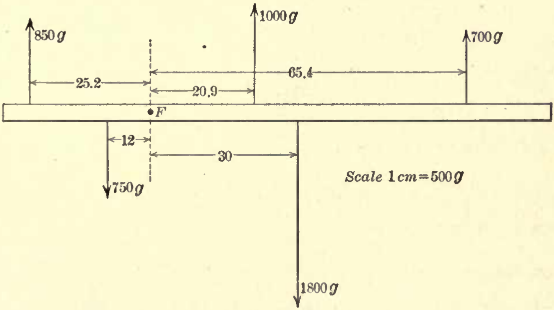

Fig. 33.

the experiment on the Principle of Moments (see Fig. 30, page 78). The balances should then be strained and clamped in place in such a way as to make all the cords parallel, and at right angles to the meter stick.

The amounts of various forces and their lever arms are to be recorded near the top of the left-hand page in the form of a diagram like that shown in Fig. 33. Letter the forces in order from left to right.

Take for the center of moments some point which is *not* the point of application of any of the forces. The line representing each force should be drawn to a scale to be designated by the instructor and the exact amount of the force should be noted at the right of the line representing it. The lever arms are indicated by dimension lines as shown. No drawing of the apparatus will be necessary. A short description, however, of the experimental method should be written.

Place a table like the following at the top of the right-hand page and make all calculations on that page:

CALCULATED RESULTS

CLOCKWISE MOMENTS		COUNTERCLOCKWISE MOMENTS	
Moment of A	----	Moment of B	----
etc.	----	etc.	----
Total clockwise moments .	----	Total counterclockwise moments	----

Sum of forces as A, C, E, etc. . . . . ----

Sum of forces as B, D, etc. . . . . ----

Conclusion:

Fill in the blanks in the following statement so that it agrees with your results:

When a number of parallel forces act on a body, it is in equilibrium when the ----- of the forces in one direction equals the ----- of the forces in the other direction, and the total ----- moments equal the total ----- moments about *any* point taken as fulcrum.

EXPERIMENT 22

Four Forces at Right Angles

OBJECT. When four forces at right angles in one plane produce equilibrium, to compare *(a)* the force in any one direction with the force in the opposite direction; *(b)* the clockwise moments with the counterclockwise moments.

APPARATUS. Composition-of-force board with under side resting on four steel balls or marbles; four pegs; four spring balances (2000 g.) with cords and clamps; meter stick or other metric ruler.

Introductory:

Four boys of different ages might pull on the four sides of a piece of burlap so as to stretch it parallel to the top of a barrel of vegetables while their father finished the heading by putting on a hoop. Each boy probably took hold of the burlap at the center of his side, but one or more of them soon found it advisable to move his hands to one side or the other of the center, so as to prevent the burlap from being drawn out of his hands. When the burlap was properly stretched, four pulls or forces were acting at right angles in one plane. Did the principle of moments come to the aid of the smaller boys in the family so that they could do their share of the stretching?

Experimental:

The hook of each spring balance is to be attached by a cord to a peg on the composition-of-force board. The pegs should be arranged so that no two of them will be in the same row of holes across the board in either direction. The other end of each spring balance is to be securely clamped (see Fig. 35 on page 89) so that both the cords holding it are parallel to a row of holes (Fig. 34). This

latter figure shows the method of attachment of the balances to the board, but not the correct location of the pegs. The strain on each balance should be at least 500 grams, and the board, which is free to move on its roller bearings, should be brought to rest by the equilibrium of the four forces at right angles pulling on it.

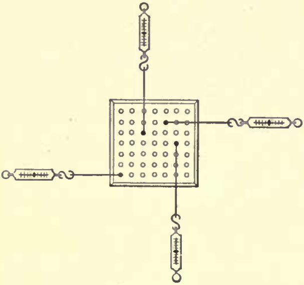

Fig. 34.

The amounts of the various forces and their lever arms are to be recorded in the form of a diagram on the left-hand page. Draw, in about the middle of this page, a square, 7 centimeters on a side, and divide each side into centimeter divisions, and *lightly* rule such cross lines as will locate the positions of the four pegs or points of application of the several forces.

Take for the center of moments some point which is *not* the point of application of any of the forces. *To a scale designated by the instructor*, draw a line representing the direction and the exact amount of each force. Indicate the amount of each force by figures placed to the right of the line representing it. The lever arm of each force is to be indicated by a dimension line as in Fig. 33, on page 83.

Calculated Results

Clockwise Moments		Counterclockwise Moments	
Moment of	----	Moment of	----
etc.	----	etc.	----
		Total counterclockwise	
Total clockwise moments .	----	moments	----

Unless the instructor so directs, make no drawing of the apparatus. A short description of the experimental method, however, should be written.

Place a table, like the one on page 86, at the top of the right-hand page and make all calculations on that page.

Conclusion:

State, when four forces at right angles in one plane produce equilibrium:

(*a*) the relation of the force in one direction to the force in the opposite direction;

(*b*) relation of the clockwise moments to the counter-clockwise moments about *any* point taken as a fulcrum.

EXPERIMENT 23

Parallelogram of Forces

OBJECT. To find the relation between three forces acting on a body at a point, in order that they may be in equilibrium.

APPARATUS. 3 spring balances (2000 g.); fish line or other light, strong cord; 3 Stone clamps or other means of holding balances in place; 30 cm. ruler.

Note.—Pencils used in this exercise should be hard, with long, sharp points.

Introductory:

If two boys were to kick a football, one east and the other north, at the same instant, the ball would not go in either direction, but would take a course somewhere between north and east. The general direction that it would take would depend upon which force were greater. To prevent the football from moving, it would be necessary

to apply a third force which should have the proper direction and amount to just neutralize the other two. We wish to find the relation between three forces at an angle to each other, acting on a body at a point in such a way as to keep the body at rest. With the football it would be possible for a single force to be substituted for the forces applied by the two boys. Such an imaginary force is known as a *resultant* force, and the two forces which it replaces are *component* forces. The single force that would keep the ball from moving is called the *equilibrant* force. Our problem is to find (*a*) how the resultant force is related to the component forces in *direction* and *magnitude;* (*b*) how the resultant force is related to the equilibrant force.

Experimental:

Connect the three spring balances by three cords that meet at a point *A*. Fasten these balances in place by clamping the attached wires. Pull on the third balance until the pointer on one of the balances is near the end of the scale and then clamp the third balance in place.

Place the right-hand page of the note-book under the cords with the center of the page under the point *A*. Mark two points directly beneath each cord. Remove the book and through each pair of points draw a line which represents *in direction* the force. Note and record on the diagram, the reading of each balance, calling the balances *B*, *C*, and *D*. Measure from *A* along each line a distance to represent the magnitude of the force, using a scale of 1 cm. to 250 grams. Place at the end of each line an arrowhead to show the direction of the force.

Select one force as the equilibrant and lay off from *A* the resultant equal and opposite to the equilibrant. On the two lines representing the components, erect a parallel-

ogram and draw the diagonal from A. Determine the magnitude of the force which this diagonal would represent. Compare it with the resultant which you laid off and drew.

Mark on the drawing the lengths of the lines and the readings of the balances. No table of results is necessary

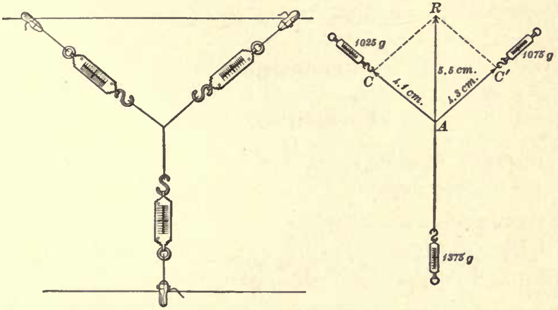

Fig. 35.

on the left-hand page, but write a simple description of the method of the experiment. The drawing has already been placed on the right-hand page.

On the second right-hand page place the table of calculated results.

Calculated Results

Magnitude of resultant . . . . *g.*
Magnitude represented by diagonal . . . . *g.*

Discussion:

(1) What single force would alone produce the same effect as the two forces represented by the sides of the

parallelogram? (2) Compare the resultant and the diagonal of the parallelogram in direction and in magnitude.

Conclusion:

Three forces are in equilibrium when the _____ of two of them is _____ in magnitude and _____ in direction to the _____.

EXPERIMENT 24

Resolution of Forces

OBJECT. **Given the resultant of two forces and one of the forces, to find the other force.**

APPARATUS. 2 spring balances (2000 g.); 500-gram weight; fish line; upright, with ring for cord and notch for boom; light hard-wood boom, about 25 cm. long, with a brad in the end.

Introductory:

When a load is hanging from the boom of a derrick, its weight is sustained jointly by the tension of the rope supporting the end of the boom and the outward thrust of the boom. These two forces may then be considered as the component forces, whose resultant balances the weight of the load. If we know the pull on the cord supporting the boom and the weight of the load, we can calculate the thrust of the boom outward.

Experimental:

(*a*) The apparatus is to be set up as shown in Fig. 36. The boom should be horizontal, and when it has been made so, a turn of the cord around the brad in the end of the boom will keep it from slipping. When all adjustments have

been made, hold the note-book with the right-hand page against the boom, and indicate the direction of the forces by dots under the cords and a line drawn along the top of the boom. Place a dot at the end of the boom, immediately under the brad. Leave the apparatus undisturbed while performing the operations of part (*b*).

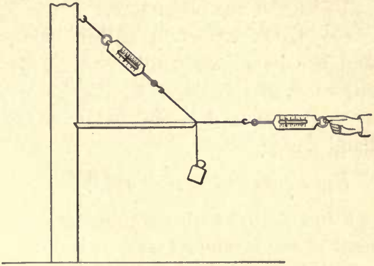

Fig. 36.

(*b*) Replace the note-book on the table. From the dot marking the common point of application of the forces, draw lines through the dots that were placed under the cords. From the common point of application, continue outward some distance the line drawn along the boom. Lay off on the line representing the tension, a distance corresponding to the reading of the balance, using a scale of 100 grams to the centimeter. Mark the end of the measured distance with an arrowhead, indicating the direction of the force. Do the same on the line representing the weight. Mark beside each line the exact number of grams represented.

The weight is the equilibrant of the tension of the cord and the outward push or thrust of the boom against the cord. Therefore draw a line upward from the point of application equal in length to the line representing the weight. With this line as a diagonal and the line representing the tension as one side, complete a parallelogram having a side extending outward from the point of application, as a continuation of the line drawn along the boom.

This side will represent the thrust in direction and magnitude. From the length of this side, the outward thrust of the boom may be calculated, using the scale employed in laying off the other lines.

(*c*) Hook a second spring balance between the cord and the boom and pull horizontally until the boom just slips out of the notch in the upright. Read the balance at this point and record below the drawing on the right-hand page:

Force required to pull out boom . . . . g.

Since action and reaction are equal, the inward component of the stretched cord on the boom must equal the outward thrust of the boom on the cord.

Make a simple sketch of your apparatus and write a brief description referring to the sketch.

Discussion:

May the resultant of two forces ever be less than one of them?

Is a rope that is just strong enough to lift a weight vertically, strong enough to lift that weight by means of a horizontal boom derrick?

Conclusion:

Given the resultant of two component forces and one of the components, state how the other component may be found.

EXPERIMENT 25

Force at the Center of Gravity of a Body

OBJECT. To find what is the gravitational force acting at the center of gravity of a body.

APPARATUS. Half meter stick loaded at one end;[1] ruler or other fulcrum properly supported (see Fig. 37); 200-gram weight with loop of cord attached; spring balance, or platform balance; metric weights.

Introductory:

When we shut a heavy door, we push near the outside of the door and not near the hinge. A small boy can balance a large boy on a seesaw, by sitting farther out on the board. When a body is to be turned about an axis, the turning power depends upon how much force is exerted and how far from the axis the force is exerted. The *turning power* of a force is called the *moment* of that force and is measured by the product of the force and its distance from the axis. The moment of the small boy on the seesaw is equal to the moment of the large boy. If we know the moment of the large boy and the distance of the small boy from the fulcrum, we can calculate what the small boy weighs. If both boys get off, the board can be balanced so it will not touch at either end. The point at which a body must be balanced in order to support it is called the *center of gravity* of the body.

Experimental:

The body will be a half meter stick loaded at one end. This is first to be balanced over a fulcrum in order to find

[1] The loading may be done by attaching a strip of brass, iron, or lead to one end of the half meter stick, at right angles to the stick.

the center of gravity (Fig. 37, *A*). Then a 200-gram weight will be hung about 10 cm. from the free end of the bar and the bar again balanced.

By measuring the distance of the 200-gram weight from the fulcrum and multiplying this distance by the weight (200 g.), the moment of the 200-gram weight is obtained.

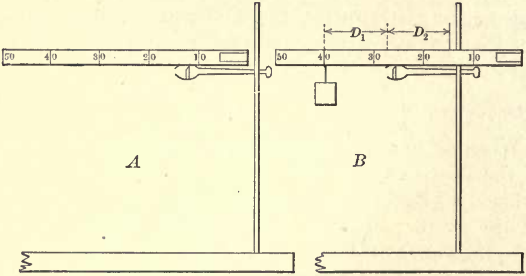

Fig. 37.

This moment equals the moment of the force at the center of gravity about the fulcrum. Then the force at the center of gravity is calculated.

A second trial should be made with the weight at some other point on the stick, as 20 cm. from the end.

Finally the loaded stick is weighed.

All observations as soon as made should be recorded in tabular form near the top of the left-hand page.

OBSERVATIONS

	1	2
Position of center of gravity of loaded stick	-----	-----
Position of 200-*g. weight*	-----	-----
Position of fulcrum for equilibrium .	-----	-----
Weight of loaded stick	-----	-----

Make drawings showing how your apparatus was used and write a simple description of how the experiment was done.

Place the table of calculated results at the top of the right-hand page.

CALCULATED RESULTS

	1	2
Distance of weight from fulcrum (D_1)	-----	-----
Distance of center of gravity from fulcrum (D_2)	-----	-----
Moment of weight about fulcrum ($200 \times D_1$)	-----	-----
Moment of force at center of gravity	-----	-----
Calculated force at center of gravity	-----	-----

Discussion:

Define *moment of force.* Explain the calculation of the moment of the force at the center of gravity and the calculation of the amount of this force.

Conclusion:

What gravitational force acts at the center of gravity of a body. (Compare the last item in both tables.)

EXPERIMENT 26

The Pendulum

OBJECT. To observe the effect on the number of vibrations of a pendulum in one minute of (*a*) change in mass, (*b*) change in amplitude, (*c*) change in length.

APPARATUS. A wood and a metal ball each about 1 inch in diameter and having a light cord about 125 cm. long attached; a support consisting of a split cork in a burette clamp, or a special pendulum clamp, so placed that the pendulum may swing freely in front of the laboratory table; metronome or laboratory clock with telegraph sounder.

Note. — Some instructors prefer to have all pendulums in the room released at a given signal and stopped on signal at the end of the minute, as confusion is thereby lessened and the student's mind is concentrated on the counting.

Introductory:

When a clock goes too fast, should the pendulum be shortened or lengthened? We see pendulums made of different materials. Does this affect the length of their beats? Does it take a pendulum longer to swing through a long arc than a small one? These are some of the questions the experiment will help to answer. By a *vibration* of a pendulum is meant a swing from one end of its arc to the other. The *period* of the pendulum is the time that one vibration takes. A *seconds pendulum* is one that swings from one end of the arc to the other in just one second; a half seconds pendulum makes one vibration in one half second; etc. The *frequency* of the pendulum is the number of vibrations per minute.

Experimental:

There will be furnished a metal and a wooden ball of the same size, attached to a light cord over a meter

long. As the suspending cord is very light, we neglect its weight and consider the length of the pendulum as the distance from the lower edge of the support to the center of the suspended ball or "bob."

For the first test, adjust the length of the pendulum with the wooden ball to 100 cm. Count and record the number of vibrations made in one minute swinging through a small arc. Replace with the metal pendulum and find how many vibrations that makes in one minute swinging through the same arc. Comparing these numbers will show whether or not the material of the pendulum affects the period of vibration.

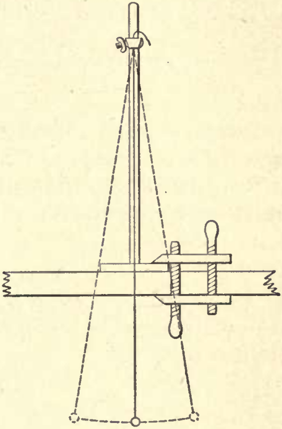

Fig. 38.

Now swing the metal bob through an arc twice as great as before, counting the number of vibrations per minute. Make the length of the pendulum 50 cm. and find the number of vibrations per minute. Repeat with lengths of 36 cm. and 25 cm.

Record all observations in tabular form near the top of the left-hand page.

Observations

Vibrations per minute, bob wood, length 100 *cm., arc small* . . . . -----

Vibrations per minute, bob metal, length 100 *cm., arc small* . . . . -----

Vibrations per minute, bob metal, length 100 *cm., arc large* . . . . -----

Vibrations per minute, bob metal, length 50 *cm., arc small* . . . . -----

Vibrations per minute, bob metal, length 36 *cm., arc small* . . . . -----

Vibrations per minute, bob metal, length 25 *cm., arc small* . . . . -----

Make a drawing of your apparatus and describe briefly how the experiment was done.

Place the table of calculated results at the top of the right-hand page and directly below make all the calculations called for.

CALCULATED RESULTS

LENGTH	NUMBER OF VIBRATIONS	PERIOD	SQUARE OF PERIOD
100 cm.			
50 cm.			
36 cm.			
25 cm.			

Conclusion:

(*a*) Does the mass of the pendulum affect the period? (*b*) Does the amplitude (if comparatively small) affect the period? (*c*) Is there any simple relation between the period and the length? between the square of the period and the length?

EXPERIMENT 27

The Inclined Plane

OBJECT. (*a*) To compare the work done in raising a load by means of an inclined plane and in raising it vertically; (*b*) to determine the mechanical advantage from the length and height of the plane.

Note. — Only the case when the force is *parallel* to the plane is considered in this experiment.

APPARATUS. Inclined plane properly supported; car with cord attached; 500-gram weight or other load; spring balance (2000 g.).

Introductory:

Safe movers roll a safe into a wagon along a sloping plank. Does this require less force than to lift the safe directly into the wagon? Is less work done by rolling it up the incline than by lifting it directly? The plank is an example of the use of the inclined plane. We wish to answer the above questions by using a car on an inclined board in the laboratory. We also wish to find out the *mechanical advantage* of the plane. This is the number which is obtained by dividing the resistance by the effort. In the inclined plane the mechanical advantage may be found also from the dimensions of the plane. We shall seek to find what dimensions are used and what division is made to obtain the mechanical advantage.

Experimental:

An iron car loaded with a 500-gram weight will be used and it is to be pulled up an inclined plane by means of a cord attached to a spring balance. This balance thus measures the force employed to draw the car up the plane.

The combined weight of the car and its load is the weight lifted by the use of the plane. It may be found with the spring balance. The dimensions of the plane are to be measured, as shown in Fig. 39.

Correction is to be made for some friction. This may be eliminated by averaging the reading of the balance when the car is moving uniformly up the incline with the

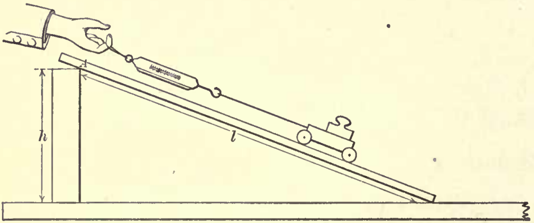

Fig. 39.

reading when it is moving uniformly down the plane. *Decide in each case whether the friction is a help or a hindrance.* The work done along the plane is measured by the product of the balance reading and the length of the plane (to A). The work done in raising the weight an equal distance is measured by the product of the weight lifted and the height of the plane (at A).

Record the observations in tabular form near the top of the left-hand page.

Observations

Weight of car and load	*g.*
Force required, car ascending	*g.*
Force required, car descending	*g.*
Length of plane	*cm.*
Height of plane	*cm.*

Make a simple sketch of your apparatus and write a short description of the method of the experiment.

Place the table of calculated results at the top of the right-hand page.

Calculated Results

Average force used	*g.*
Work = *weight lifted* × *height of plane* . . .	*g.cm.*
Work = *force* × *length of plane*	*g.cm.*
Mechanical advantage = $\frac{\textit{weight}}{\textit{force}}$	
$\frac{\textit{Length of plane}}{\textit{Height of plane}}$	

Conclusion:

(*a*) Compare work done in lifting the load *vertically* from the table to the level of *A*, with the work done in raising it the same vertical distance by rolling it along the plane. (*b*) What relation between the height and length of the plane equals the mechanical advantage?

EXPERIMENT 28

Pulleys

OBJECT. To study the operation of pulleys and to find their mechanical advantage.

APPARATUS. 1 single fixed pulley and 1 double fixed pulley with stems for clamping or attaching; single movable pulley; an additional movable pulley or a movable double pulley with hooks for suspending pan or weights; support for fixed pulley; balance pan[1]; metric weights; spring balance (250 g.); meter stick; light, strong flexible cord (fish line).

Introductory:

The block and tackle is a familiar sight in large cities, as it is used for moving pianos and safes in and out of high buildings. In the country it is used for pulling stumps and handling logs. On the water front, the pulley in some form or combination is employed for loading the heaviest articles of the cargo.

Pulleys would not be so widely used unless they brought some mechanical gain to their users. The mechanical advantage of a machine may rest in changing either the direction or the magnitude of the force applied to it. Wherein lies the gain when pulleys are used?

[1] The balance pan for *Part* (*a*) is made by first finding with a sensitive spring balance the error in indicated weight arising from the use of the balance tested in an inverted position. The pan is made from thin sheet copper and holes punched in the corners for the fine copper wire used as suspension cords. The weight of the pan and its suspension should equal the weight error found for the balance. It can be adjusted by filing or punching.

Experimental:

(*a*) *The Fixed Pulley.* A spring balance should be used with the hook downward, as the weights of the hook and the drawbar were acting on the spring when the mark for the zero point was located. In an inverted position the balance will not read correctly. To compensate for the error arising in this manner, in this experiment, the balance pan with its supporting cords has been made equal in weight to the drawbar and hook.

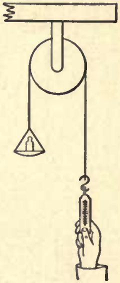

Fig. 40.

The apparatus should be arranged as in Fig. 40. A weight is placed in the pan and the spring balance is pulled vertically downward so as to raise the load at a steady rate, the force or effort necessary being read at the same time on the spring balance. Then the balance reading is again taken as the load descends at a uniform rate. The friction increases the balance reading as the load ascends and decreases the reading for the load descending. An average of the two readings may be considered as the force or *effort* which will just equal the *resistance* to be overcome before the load will move.

Take readings with 100 grams and 200 grams as the loads, and record in tabular form. Note the distance through which the load is raised as compared with the distance through which the effort moves. Compare the load with the effort. *What is the only mechanical gain in using a single fixed pulley?*

(*b*) *Single Movable Pulley.* The apparatus is arranged as in Fig. 41. The total load in this case includes the weight of the pan and the weight of the pulley block. These are weighed separately and the weights recorded.

Readings are made with the 100-gram and the 200-gram weights as in (*a*). How does the distance through which total load (resistance) moves compare with the effort distance? *What is the*

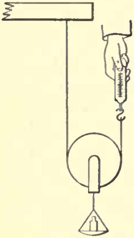

Fig. 41.

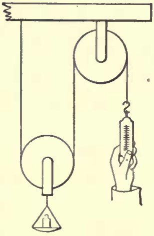

Fig. 42.

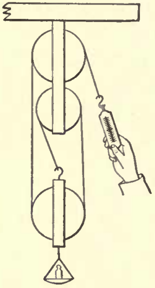

Fig. 43.

mechanical advantage of a single movable pulley? What is sacrificed to gain this?

(*c*) *Combinations of Pulleys.* — A *single fixed* and a *single movable* pulley are arranged as in Fig. 42. This is the arrangement used in the movable scaffolds of house painters. Only one set of readings is made — that with a load of 200 grams. *What additional advantage does this combination of pulleys have over the single movable pulley?*

Next, *two fixed* pulleys (a double pulley) and a *single movable* pulley are combined by the proper adjustment of cords. Readings are taken with the 200- and the 500-gram weights. The vertical distance through which the load moves from the table top is carefully measured as is also the distance covered by the effort at the same time. Note also the number of cords which support the movable block.

Then a *fixed pulley* is combined with *two movable pulleys*

(or a double pulley) and a similar set of readings taken with weights of 200 and 500 grams.

Make for (*a*), (*b*), and (*c*) simple diagrams showing the arrangement of the load, the pulleys, and the spring balance. Indicate clearly the number of cords which support the movable pulley blocks.

Write simple descriptions of the work done in each part of the experiment, shortening the descriptions by references to the diagrams.

Observations

Trials	Pulleys used	Weights of			Balance Reading	
		Load	Pan	Movable Block	Up	Down
1 and 2	1 fixed	100 g.	——	——		
3 and 4	1 fixed	200 g.	——	——		
5 and 6	1 movable	100 g.				
7 and 8	1 movable	200 g.				
9 and 10	1 fixed and 1 mov.	200 g.	——			
11 and 12	2 fixed and 1 mov.	200 g.	——			
13 and 14	2 fixed and 1 mov.	500 g.	——			
etc.	etc.	etc.				

For Part (*c*) *only; Trials* 11 *to* 18

Number of Trials	Resistance (Total Load)	Effort (Average Balance)	Distance moved Through	
			Resistance	Effort
11 and 12				
13 and 14				
15 and 16				
17 and 18				

Except in *Part* (*a*), the total load (resistance) is the sum of the weights on the pan, the weight of the pan, and the weights of the movable blocks used. The average of the two balance readings in each trial is the effort. The *mechanical advantage* of a machine is defined as the resistance divided by the effort. Record these calculated results in a table at the top of the right-hand page.

CALCULATED RESULTS

TRIALS	PULLEYS USED	RESISTANCE (R) (Total Load)	EFFORT (E) (Average Balances)	MECHANICAL ADVANTAGE $R \div E$	CORDS SUPPORTING MOVABLE BLOCK

Discussion:

Under this heading on the right-hand page (or the second right-hand page) answer the italicized questions occurring in the experimental directions.

Conclusion:

After comparing in each case the number representing the mechanical advantage with the number of cords supporting the movable block or blocks, answer the following question:

How may the mechanical advantage of a set of pulleys be stated in terms of the machine's construction?

EXPERIMENT 29

The Wheel and Axle

OBJECT. To study the operation of the wheel and axle and to find its mechanical efficiency.

APPARATUS. Wheel and axle with several diameters; metric weights (500 g. and 1000 g.); spring balance (2000 g.) in case apparatus has not an exact simple ratio; fish line; stand and clamp for wheel and axle in case it is not mounted on its own base; pair of calipers (or a pencil compass) is convenient for measuring the radii; meter stick.

Introductory:

The windlass is used to lift a bucket from a well or dirt from an excavation. Several men on a capstan can pull out of the water a heavy anchor which they could not lift with their hands from the deck of the vessel. The devices for accomplishing these rather difficult tasks are applications of the wheel and axle, one of the simple machines. In the illustrations just given, a lesser effort overcomes a larger resistance, or there is a mechanical advantage greater than one. Upon what does the mechanical advantage of a wheel and axle depend?

Experimental:

One cord is attached to the axle and another cord to the wheel. On the axle cord is attached the load (*resistance*); on the wheel cord are attached weights which act as the *effort* and just balance the load. When the weights on the two cords are in equilibrium, *the slightest pull on the cord in either direction should make the weights run freely up and down at a gentle rate.*

The weights may be attached by a slip noose in the

free end of the cord. The first load may be conveniently 1000 grams. The distances traveled by the effort and the resistance in the same time are measured with a meter stick. The radius of the axle and the radius of the wheel are also determined. All these measurements are to be recorded in tabular form near the top of the left-hand page.

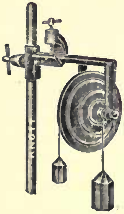

Fig. 44.

At the direction of the instructor, measurements with additional loads are made. In case there are several wheels on the axle, one of the smaller wheels may be taken for a new axle. For some of the measurements it may prove necessary to use a spring balance in place of the effort weight.

Observations

Number of Trial	Load on Axle (Resistance)	Effort on Wheel	Radius of Axle	Radius of Wheel
1	1000 g.			
2				
etc.	etc.			

For Two Readings Only

Number of Trial	Load (Resistance)	Effort	Distance Moved Through	
			Resistance	Effort

Make a drawing of the wheel and axle used and write a simple description of how the experiment was done.

The mechanical advantage of a simple machine like the wheel and axle, is *the ratio of the resistance to the effort.* Calculate this for each trial. Also find in each case *the ratio of the radius of the wheel to the radius of the axle.* Place all the calculated results in tabular form at the top of the right-hand page.

CALCULATED RESULTS

NUMBER OF TRIAL	RESISTANCE (R) (Load)	EFFORT (E)	MECHANICAL ADVANTAGE $R \div E$	$\frac{\text{RADIUS WHEEL}}{\text{RADIUS AXLE}}$

Discussion:

What is sacrificed in gaining the mechanical advantage of the wheel and axle?

Conclusion:

Complete the following statement: The mechanical advantage of the wheel and axle may be stated in terms of its construction as the ratio of the ---------------- to the ----------------

EXPERIMENT 30

Mechanical Efficiency of Machines

OBJECT. — To find the mechanical efficiency of an inclined plane, a set of pulleys, and a wheel and axle.

APPARATUS. As designated for the inclined plane (page 99), for the pulley (page 102), and for the wheel and axle (page 107).

In the experiments on those machines, measurements were made and tabulated which will serve for this experiment.

Commercial block and tackle with necessary weights in case Part (*b*) is to be done.

Introductory:

The rapid growth of the manufacturing industries in the United States has been due in large part to the development of efficient machinery. To be efficient, a machine must return, in some form of useful output, a large part of the energy applied to it. Machines which waste too much of the applied energy in friction, in loss of motion, or in other ways, are condemned to the scrap heap when a more efficient machine for the same purpose is devised. Calculations of the efficiency of complicated machinery are difficult even for a competent mechanical engineer, but a student can learn from the inclined plane, the pulley, and the wheel and axle, the main factors in the efficiency of any machine. These factors are in accordance with the *law of work*, — "the amount of work put into a perfect machine equals the work gotten out of it."

The *mechanical efficiency* of a machine is the percentage of total work done on the machine which proves useful.

Experimental:

(*a*) The instructor may direct the use of the readings obtained in the experiments on the inclined plane, the

pulley, or the wheel and axle. In all cases, the effort readings used must be ones taken while the weight (resistance) is being *raised*, *without correction for friction.* These are the conditions under which a machine does *useful* work.

The weight raised, the height of the plane, the force with load ascending, and the length of the plane are the readings to be taken from the inclined plane experiment.

It should be noted with regard to the inclined plane that the load (resistance) moves through a *useful* distance equal to the height of the plane while the effort is moving the length of the plane. The effort is the force used with the load ascending.

In the pulley and the wheel and axle experiments, most of the readings necessary for this experiment were tabulated in the second table of observations. The *effort* reading to be taken from the pulley experiment is not the "average balance," but the balance reading with the load ascending, recorded in the first table of observations.

The observations taken from previous experiments should be again tabulated near the top of the left-hand page used for this experiment. Any new observations made at the direction of the instructor may be tabulated in the same form.

(*b*) During the laboratory hour, if the instructor so directs, a test will be made on the efficiency of a *commercial* block and tackle with as large a load as is safe and desirable. The students designated by the instructor to make the test will report the results to the class. Comparison can then be made between the school apparatus, designed to show the *law* of work, and commercial apparatus, made to stand the wear and tear of actual service.

In a perfect machine, the amount of work obtained from it equals the amount of work put into it, *i.e.* resist-

ance × resistance distance = effort × effort distance. Calculate these two products for each observation.

Then calculate the mechanical efficiency of each machine from the two products, recalling that

$$\text{Efficiency} = \frac{\text{useful work (work output)}}{\text{total work (work input)}}.$$

Observations

Machine	Resistance (Load or Weight lifted)	Effort (Force applied)	Distance moved through	
			Resistance	Effort

At the top of the right-hand page tabulate the results of all calculations.

Calculated Results

Machine	Useful Work (Resistance × Resistance Distance)	Total Work (Effort × Effort Distance)	Mech. Efficency $\left(\frac{\text{Useful Work}}{\text{Total Work}}\right)$

Discussion:

What may make the mechanical efficiency vary in different observations of the same machine?

Conclusion:

The *average* mechanical efficiency found from my observations was for the inclined plane ...... %, for the ...... pulleys ...... %, and for the wheel and axle ...... %.
(state combination used)

EXPERIMENT 31

Coefficient of Friction

OBJECT. To determine the ratio of the friction between two surfaces to the pressure holding them together.

APPARATUS. Rectangular wooden block; board with uniform surface, with support for use as inclined plane; spring balance (2000 g.); fish line; block of weights; meter stick.

Introductory:

Heavy loads on a wagon press down and increase the friction at the axles. The ratio between the friction and the pressure causing it, is called the *coefficient of friction.*

This fraction has different values according to the kinds of surface in contact. For instance, there is more friction between rubber soles and a polished floor than between leather soles and the same floor. The man with the rubber soles can walk up a steeper plank, but even he will begin to slip when the pitch of the plank is increased to a certain definite angle. The leather soles slip at a smaller definite angle of pitch.

The coefficient of friction may be found, either by measuring both friction and pressure directly, or by finding the angle of elevation of the surface of one body, at which the weight of a second body will just cause the latter to slip down the inclined surface of the first.

Experimental:

(*a*) A hard wood block, with various weights upon it, is dragged over the surface of a smooth horizontal board by means of a cord attached to the block and to a spring balance. If the block is kept moving at a uniform speed,

the reading of the balance will show the amount of the friction between the surfaces. The pressure between the

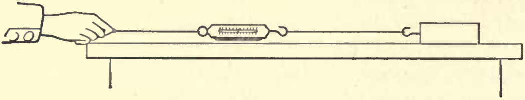

Fig. 45.

surfaces is the weight of the block *plus* the load placed upon it. Several weights ranging from 100 to 1000 grams should be used to load the block. From these readings the coefficient of friction may be found by dividing the friction by the pressure causing it.

(*b*) Using the same block and board, with a support to adjust the board to any desired inclination, the board may

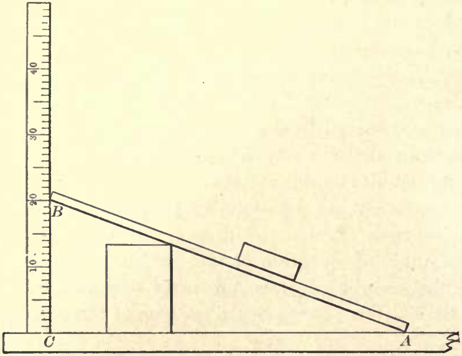

Fig. 46.

be raised gradually until the unloaded block will just slide down with uniform motion if the board is constantly tapped with the finger. This angle is called the *limiting*

angle of friction. Referring to Fig. 46, AC and BC should be measured.

When a body rests on an inclined plane, its weight, w, is resolved into two component forces. One of these, p, is perpendicular to the plane and produces pressure upon it. The other component f acts parallel to the plane and toward the lower end. As this is the only component of the force that acts in the direction in which the body on the plane may move, it is evident that only this force needs to be balanced to keep the body from moving down the plane. Therefore, at the limiting angle, the component f of the weight w, as it urges the block down the plane, just balances the friction.

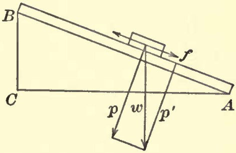

Fig. 47.

It will be readily seen (Fig. 47) that the triangles fwp' and ABC are similar. Hence, $\frac{f}{p} = \frac{BC}{AC}$. But $\frac{f}{p}$ is the friction divided by the pressure and is, therefore, the quantity we seek. Its value, then, may be calculated by dividing the height of the plane by the length of the base.

Record the readings in tabular form near the top of the left-hand page.

Observations

Part (a):

	1	2	Etc.
Total pressure (block and weight)	----- *g.*	----- *g.*	----- *g.*
Reading of balance	----- *g.*	----- *g.*	----- *g.*

Part (b):

Height of plane . . . . *cm.*

Length of base . . . . *cm.*

Make a clear outline drawing of your apparatus and briefly describe your work in both (*a*) and (*b*).

Place the calculated results in tabular form at the top of the right-hand page.

CALCULATED RESULTS

Part (a):

Coefficient of friction $\left(\frac{friction}{pressure}\right)$

1	2	3	Etc.	Average
-----	-----	-----	-----	-----

Part (b):

Coefficient of friction $\left(\frac{height}{base}\right)$ -----

Discussion:

Is the coefficient of friction dependent upon the load? Show why the ratio of the height to the base of the inclined plane at the limiting angle is equal to the coefficient of friction.

Conclusion:

The coefficient of friction between ----- and ----- is
(name materials)

-----.

EXPERIMENT 32

Vibrations of a Tuning Fork

OBJECT. To determine the frequency of a given tuning fork.

APPARATUS. A low frequency tuning fork (not over 128 V.P.S.) with considerable amplitude of vibration, preferably made of bell metal, and with a bristle or stylus attached; oval piece of wood; glass plate smoked; pendulum beating known fraction of a second, provided with a stylus; rigid clamps for tuning fork and pendu-

lum; holder and track for glass plate; candle, or cake of "Bon Ami."

Note. — Apparatus dealers furnish sets of the above apparatus.

Introductory:

A knowledge of the number of vibrations corresponding to each musical note is essential to the understanding of the Physics of Sound. While the ear may be trained to estimate very closely the pitch of the tuning fork, the eye is not quick enough to count its vibrations. By providing the fork with a tracing point and by drawing prepared glass or paper under the fork at right angles to the direction in which the fork is vibrating, each complete back and forth vibration of the fork will be represented by a wave-shaped mark. If a pendulum provided with a tracing point is so placed that it also vibrates across the glass, the distance the glass moved during the known period of the pendulum is also recorded. Then the number of vibrations of the tuning fork in that period may be counted.

Experimental:

The best way of preparing the glass is to rub over it a thin coat of "Bon Ami" or of whiting and alcohol, and allow it to dry. The apparatus should then be carefully inspected and adjusted so that the tracing points of both the fork and the pendulum will sweep across the plate in as nearly the same line as they can without interfering with each other. The tracing points must bear on the surface hard enough to scratch away the coating, but not with pressure enough to check the motion of either fork or pendulum. This may be tested by setting each in vibration with the glass at rest.

The fork is best set vibrating by placing between the

prongs an oval stick of wood, thick enough to spread the prongs the desired amount, and then suddenly pulling it out.

When all adjustments are made, set pendulum and tuning fork in vibration and with a steady, even motion draw the glass along the track at such a rate as to have

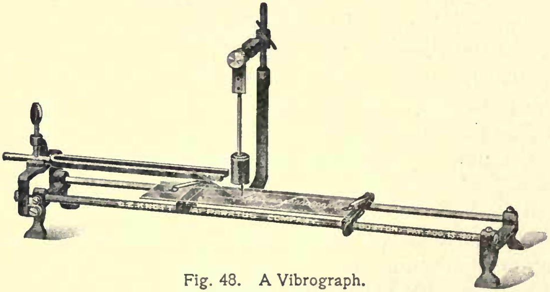

Fig. 48. A Vibrograph.

at least one complete swing of the pendulum, back and forth, recorded on the glass. Remove the glass, to permit others to use the apparatus.

The number of *complete* wave forms traced by the fork between two *successive* points where the pendulum wave crosses the tuning fork wave, is the number of vibrations made by the tuning fork in the period of the pendulum.

Place in tabular form, near the top of the left-hand page, the time of the pendulum period and the number of vibrations recorded each time during that period.

Observations

Trial	1	2	3	4
Observed vibrations .	-----	-----	-----	-----
Period of pendulum .	-----	-----	-----	-----
Number of fork . . .	-----			

Make a simple drawing of your apparatus and describe briefly the essentials of the method.

Calculate the average number of vibrations for the period of the pendulum, and from the average find the number of vibrations per second. Record the calculated results at the top of the right-hand page.

Calculated Results

Average number of vibrations in ..... sec. was . . -----
Frequency of fork (vibrations per second) . . . -----

Discussion:

(*a*) Explain fully why a complete wave trace of the fork stands for one vibration of the fork.

(*b*) Why does a half wave trace stand for the period of the pendulum?

Conclusion:

The frequency of fork No. ...... is ..... vibrations per second.

EXPERIMENT 33

The Velocity of Sound in Air

OBJECT. To determine the approximate velocity of sound in the open air at the existing conditions.

APPARATUS. Pendulum ($\frac{3}{4}$ sec.) with large-faced bob[1] and mounted in a shallow box; pair of field glasses; measuring tape; two short pieces of board; thermometer.

Introductory:

A flash of lightning is usually seen before the thunder, the sound accompanying the electric discharge, is heard. The steam escaping from the whistle on a distant locomotive may be noticed several seconds before the sound reaches our ears. The flash of a gun is evident before the sound of the discharge is heard. All these illustrations show that sound travels much more slowly than light, and that an appreciable interval is required for a sound to travel any considerable distance. Since light has such great velocity, the time required for it to travel a part of a mile is not measurable by any ordinary means, while the comparatively slow-traveling sound takes a noticeable time for the same distance. These relative velocities make possible a simple method for determining the number of feet per second traveled by a sound.

Experimental:

Mount the pendulum beating three fourths of a second in a shallow wooden box with the cover removed. Stretch

[1] In case a pendulum with a brass bob is not available, a pendulum may be made with a 5-lb. slotted weight and a wooden bar, or a good bob could be cast of lead with a small brass curtain rod inserted, in the cover of a coffee tin or lard pail. Whatever large-faced bob is used, one face should be painted a blue similar to that used in the enameled street signs.

across the box opening an opaque white cloth and in it make a hole the shape and size of the pendulum bob at the center of its vibration. At the back of the hole and on the bottom of the box arrange a white background. The exposed face of the bob should be painted blue, since this color will be readily seen as the bob swings across the opening.

Set the pendulum about 500 feet away, so placed that the bob of the pendulum is several feet from the ground. One student is stationed at the box with two short boards and strikes them together so as to produce a sharp sound every time the bob is at the center of its swing.

Observers should move either toward or away from the pendulum until a position is obtained where the successive sounds produced coincide with the successive swings of the bob across the opening. This means that the sound produced at the center of one beat of the pendulum reaches the observer at the center of the next beat. Then during the time of one beat, the sound travels the distance of the pendulum from the observer. Field glasses will be necessary to see clearly the swing of the bob across the opening.

Make one determination with the wind, and one against it, and record the distances as measured with a tape.

Take the temperature of the air and record in the table of observations.

Observations

Distance of observer to pendulum, with wind . *ft.*
Distance of observer to pendulum, against wind *ft.*
Temperature of air . . . . °*C.*

Make drawings showing how the pendulum was set up and describe the method of the experiment.

CALCULATED RESULTS

Average distance traveled by sound in $\frac{3}{4}$ second *ft.*
Velocity of sound per second . . . . *ft.*

Conclusion:

The velocity of sound per second in the open air at ..... ° *C.* was ....

EXPERIMENT 34

Sympathetic Vibrations

OBJECT. To set a tuning fork into vibration by sympathetic vibrations with another fork of the same frequency.

APPARATUS. Two tuning forks of the same frequency,[1] as 256 V.P.S.; tuning fork of different frequency, as 384 V.P.S.; flat cork about 2″ in diameter; 500-gram weight or iron ball with fish line for suspension; support for hanging weight.

Introductory:

When the loud pedal of a piano is pressed, dampers are lifted from the strings so that the strings can vibrate freely. Then a note sung into the piano will make one wire vibrate in response, so that a note of the same pitch can be heard. The sound vibrations produced by the human voice have been the stimulus to the production of a sound by the vibration of one of the piano wires.

[1] *Note to Instructor.* — Two forks stamped with the same frequency number will rarely vibrate at the same rate without filing notches in the end of one of them. Do this by taking two forks that sound nearly alike and than raise the pitch of the lower (flat) fork by filing the outer end of one prong. Then stamp or file an identifying number on the handle of both forks. Always give out together that pair of forks for this experiment.

Since the stimulating sound and the sound produced have the same pitch (frequency of vibration), this is a case of *sympathetic vibrations*. Tuning forks are very convenient instruments for studying sympathetic vibrations, for their rate of vibration per second is known. Usually the frequency number is stamped at the base of the two prongs.

Experimental:

(*a*) Suspend a 500-gram weight (or a ball of about the same weight) by a light, strong cord about a meter in length.

When the weight is at rest, give it a light tap with a lead pencil, noting the direction in which the weight begins to move or vibrate. When the weight is at the center of its swing and *moving from you*, tap again. Continue in this manner until the weight has received about twenty gentle taps. What is the effect upon the vibrations of the suspended weight? From what source did the weight get its impulses?

With the weight again at rest, give it, without paying any attention to the intervals, twenty more gentle taps, hitting the weight just as it happens to be coming toward or going away from you. What is the effect on the vibration of the weight? Compare the regularity in time of this second tapping with that of the first. *What relation existing between the regularity of the tapping and the vibration of the weight, caused such a marked effect in the first case?*

(*b*) The following directions must be followed exactly in order to secure the desired result. Study them thoroughly before beginning the experiment. Examine the forks to see that the same number is marked on the stem of each.

(1) Hold the two forks by the stem, not allowing the

fingers to touch any other part of the fork (in order to avoid heating).

(2) Set the fork held in the right hand into vigorous vibration by striking the end of one of its prongs sharply against a cork on the desk.

(3) Steady the fork in the left hand by allowing the hand to rest against the desk with the fork held horizontally.

Fig. 49.

(4) Bring the vibrating fork into a position parallel to the other fork, with the prongs extending in an opposite direction and the two forks about $\frac{1}{16}$ of an inch apart (Fig. 49).

(5) After the forks have been in this position while you count three, slowly bring the left-hand fork near the ear and determine whether it has been set into vibration.

(6) If the first trial has not been successful, repeat the work.

Apply to the instructor for a tuning fork of different frequency from that of the two forks used. With this fork and one of the former ones repeat the experiment, noting the success of your efforts.

Make a drawing showing the forks in the position where sympathetic resonance was obtained. Write a full description of the experiment and its results.

Conclusion:

Answer the italicized question in Part (*a*). What must be true of the frequencies of two forks in order that one of them may be set into sympathetic vibration by the other?

EXPERIMENT 35

The Wave Length of a Sound

OBJECT. To determine, at the temperature of the room, the length of a sound wave from a C tuning fork (256 V.P.S.).

APPARATUS. Glass resonating-tube about 12″ long and 1″ to $1\frac{1}{4}$″ in diameter, with lower end closed by a 1-hole rubber stopper carrying a glass delivery tube with rubber connection and pinch-cock between the two sections; beaker; ring stand and clamp with jaws lined with cork; C tuning fork, 256 V.P.S.; flat cork about 2″ in diameter.

Introductory:

When a prong of a tuning fork is vibrating, the prong makes a forward and a backward movement in completing one vibration. The vibrating prong sets the adjacent air vibrating longitudinally, and finally the sound wave reaches our ear. By using a glass tube with the lower end closed by water, we get a vibrating air column whose length can be readily measured. When the vibrating fork is held over the open end of the tube, the air column within is set into vibration. The sound wave starting from the prong travels down the tube to the water surface, where it is reflected and travels back again to the vibrating prong. By varying the length of the air column, it is found that a column of certain length greatly intensifies or reënforces the sound of the tuning fork. This reënforcement or resonance is due to the reflected wave adding its sound to the sound being produced by the vibrating prong. To get the maximum intensification or resonance, the impulse started by the forward movement of the prong must travel down the tube and back again in time to reënforce the prong in its backward motion. Thus during the first

half vibration of the prong, the sound produced by it has traveled twice the length of the air column. During a *whole vibration* the sound would travel *four times the length of the air column.* The distance traveled by a sound, while the body producing it is making one vibration, is the wave length of that sound. From this discussion it can be seen that *the length of the vibrating air column is one quarter the wave length of the sound when the air column is adjusted to the point of maximum resonance.*

Experimental:

Arrange the apparatus as in Fig. 50. To avoid disturbing sounds, the jaws of the clamp should be lined with cork and the delivery tube should always be dipping into the water of the beaker.

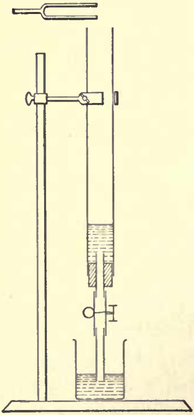

Fig. 50.

Start with the resonating tube nearly full of water, and, by letting the water out slowly through the delivery tube, find a level which will give the strongest reënforcement of the sound emitted by the fork. In making this determination, set the fork vibrating loudly by striking it on the large cork, and hold the fork just over the top of the tube with the prongs *parallel* to the surface of the water. In case too much water runs out of the resonating tube, pour some back from the beaker. In order to determine whether it is your air column or that of your neighbor which is sounding, keep moving your fork over the mouth of the tube and then away from the tube.

When the *precise* level for the *loudest* resonance is found, measure in inches the length of the air column for this position and the internal diameter of the tube.

Keeping the same fork, exchange the rest of your apparatus for that of another student and make a second determination of the level of loudest resonance. Measure as before and record.

In the tabular form near the top of the left-hand page record the vibration number stamped on the fork and also the temperature of the room.

Observations

	I	II
Length of resonant air column	-----	-----
Internal diameter of tube	-----	-----
Frequency of fork (vibration number) .	-----	-----
Temperature of air of room	-----	-----

Make a drawing of your apparatus, showing the position of the fork and the length of the air column at the point of maximum resonance. Write a simple description of how the experiment was done.

The measured length of the air column is not quite correct for the distance traveled by the sound in one quarter of a vibration. It actually travels a little farther, owing to the reflection from the sides of the tube and the spreading at the open end. Adding 0.4 of the diameter of the tube to the length makes the necessary correction.

Calculated Results

	I	II
Correction for air column (0.4 d'am.) .	-----	-----
Corrected length of air column . . . . (*length* + 0.4 *diameter*)	-----	-----
Wave length produced by fork in air . . (4 × *corrected length*)	-----	-----

Discussion:

By reference to a lettered diagram showing a prong of the fork and an air column, tell why four times the length of the resonating column is taken as the wave length of the fork.

Conclusion:

The length of a sound wave from a C fork (256 V.P.S.) at ____° C. was ______ inches.
(average)

Velocity of Sound.—The wave length of sound produced by a fork multiplied by the number of its vibrations per second (frequency) gives the velocity of sound per second.

If the instructor so directs, make this calculation, using the data already obtained. Remember to divide the product by 12 in order to express the velocity of sound in feet per second at the temperature of the room.

EXPERIMENT 36

Laws of Vibrating Strings

OBJECT. To find how the frequency depends upon (*a*) the length when the tension is constant, (*b*) the tension when the length is constant.

APPARATUS. A simple sonometer, like the apparatus used in Experiment 7, page 37, modified to use with shorter wire and a meter stick; bridge for sonometer; steel piano wire, about 26 B. & S. gauge; slotted weights running to 5 kg. or about 10 lb.; tuning forks[1] C (256 V.P.S.), A ($426\frac{2}{3}$ V.P.S.), and C′ (512 V.P.S.); flat cork, 2″.

Introductory:

No form of music is more appreciated than that produced by stringed instruments. There is a fascination in watching the play of a violinist's fingers as he changes the lengths of the vibrating strings. In the preliminary tuning of the violin the strings are tightened by putting more pull or tension upon them. All these adjustments, made so readily by the practiced violinist, are in accordance with a few simple laws relating to vibrating strings. These laws may be determined in the laboratory by the use of simple apparatus and a little patient observation.

Experimental:

Arrange the apparatus as in Fig. 51, placing the bridge (*B*) about 60 cm. from the fixed end (*A*). Add enough weight to stretch the wire tight so that the wire will give a clear note when it is plucked.

[1] A G fork (frequency 384) would be recommended for this experiment in preference to the A fork, were it not for the relative cheapness of the latter.

(*a*) *Law of Lengths.* — Set the string *AB* vibrating by plucking it with your first finger. Strike a C tuning fork (frequency 256) on a flat cork, and note whether or not the fork and the wire give sounds of the same pitch. This unison can be told by the absence of beats. If the sounds are not in unison, increase the tension by adding more weight, and try again. Continue in this manner until unison is obtained, shifting the bridge a little, if necessary. Then the string and the fork are making the

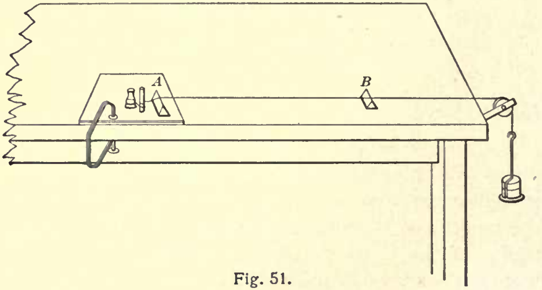

Fig. 51.

same number of vibrations per second. Measure and record the length *AB* of the string which gives 256 vibrations per second.

With the tension remaining the same, adjust the length of the vibrating string so that it is in unison with an A fork (frequency 426). Do this by moving the bridge. Measure and record the length of the vibrating wire. Is this wire which gives 426 vibrations shorter or longer than the wire with the frequency of 256?

Again vary the length of the vibrating wire so as to bring it into unison with a C′ fork (frequency 512). Measure and record. How does this length compare with

the length of a string which makes half as many vibrations per second, the tension remaining the same?

(*b*) *Law of Tensions.* — Record the weight which in Part (*a*) gave the tension on the wire with a frequency of 512. Keeping the vibrating wire the same length, gradually decrease the tension by removing weight, until the wire is in unison with the C fork (frequency 256), as nearly as the weight permits. Record the tension.

Find the ratio of the square roots of the two tensions. What else has the same ratio when the length of the vibrating string is kept constant?

If there is time, and if the instructor so directs, verify the relation just formed by putting such a tension on the wire as will make it vibrate in unison with an A fork (approximate frequency 426).

Observations

Part (*a*): *Law of lengths* (*tension constant*).

Fork	Frequency	Length of Wire in Unison
C	-----	----- *cm.*
A	-----	----- *cm.*
C′	------	----- *cm.*

Part (*b*): *Law of tensions* (*length constant*).

Frequency of Wire	Tension (Weight)
512	-----
256	------
426	------

Make a diagram of your apparatus. Describe briefly the method in each part of the experiment.

Calculated Results

Part (b):

Frequency of Wire	Square Root of Tension
512	-----
256	-----
426	----

Discussion:

What is the quickest way of raising the pitch (frequency) of a violin string? What is the effect of tightening a violin string? Explain.

Conclusion:

State (*a*) the relation of pitch (frequency of vibration) to the length of a vibrating string when the tension is constant; (*b*) the relation of pitch to the square root of the tension when the length is constant.

EXPERIMENT 37

Measurement of Candle Power

OBJECT. To determine the candle power of a lamp by means of a Jolly or a Bunsen photometer.

APPARATUS. A Jolly[1] or a Bunsen photometer; 2 incandescent lamps, one of known candle power. If electricity is not available, a standard candle and an oil lamp may be used. The ordinary paraffin candle, "6's" or "12's," are about 1.25 candle power.

Introductory:

The ordinary incandescent lamp is rated at 16 candle power. This means that it gives 16 times as much light as one standard candle. If the candle is placed on one side of a translucent screen and the lamp on the other, the screen can be moved to a position where it is equally illuminated on both sides. The screen receives the same intensity of illumination from both lights, but the greater candle power of the lamp permits it to be much farther from the screen than the candle. If the latter is 20 cm. from the screen, then the distance of the lamp will be found to be 80 cm. It is interesting to note that the

[1] The Jolly photometer consists of two slices of paraffin about 5 cm. square, cut from blocks of "Parawax," and of equal thickness, separated by a sheet of tin foil (Fig. 52). These disks are mounted at the center of a block about 18 cm. long and held in place by a rectangular hood of tin (T) nailed to the block (W) (Fig. 53). The junction of the two blocks is viewed through an opening in the tin hood, at the center of the screen. The block and hood should be painted black. The different photometers in the laboratory should be so placed that each screen receives light from its own lamps only.

The authors are indebted to Mr. W. R. Pyle of the Morris High School, New York, for the simple method of mounting the Jolly screen given above.

squares of these distances from the screen have the same ratio as the relative candle power of the two lights:

Illuminating Power of Candle		Illuminating Power of Lamp		Square of Candle Distance from Screen		Square of Lamp Distance from Screen
1	:	16	::	400	:	6400

Hence the ratio of the illuminating power of two lights equals the ratio of the squares of their respective distances from the equally illuminated screen.

The screen device for determining relative candle power is known as a photometer. Owing to the difficulty of getting candles of exact candle power, the candle power of lamps in commercial practice is usually found by comparison with standard incandescent lamps, whose candle power has been accurately determined.

Experimental:

If the photometer differs from that shown in Fig. 52, the instructor will give directions for its use. In the Jolly photometer (Fig. 52), two slices of paraffin, separated by

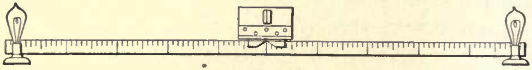

Fig. 52.

a sheet of tin foil, are used for the translucent screen. The tin foil prevents the light received from one lamp from illuminating the other side of the screen. The light is reflected instead, and intensifies the illumination in the half of the paraffin facing the lamp. When the two halves of the screen are equally illuminated, the two halves of the exposed ends will have the same shade.

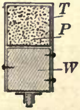

Fig. 53.

Start with an incandescent lamp of known candle power, and compare with it a lamp of unknown candle power, as follows:

(1) Place the incandescent lamp of known candle power in one socket and the unknown lamp in the other. Both sockets should be connected to the same current outlet.

(2) Slide the screen along the meter stick, until the two halves of the paraffin are of the same shade of brightness. Record in tabular form, near the top of the left-hand page, the position on the meter stick of the standard lamp, that of the unknown lamp, and that of the screen.

(3) Move the lamp away from its position and make a second independent setting. The average of each pair of distances obtained should be used in making the final calculation.

Observations

Number of Reading	Position of Standard	Position of Unknown	Position of Screen	Candle Power of Standard
1	-----	-----	-----	-----
2	-----	-----	-----	-----

Make a drawing, showing the essential parts of the photometer, and describe how you used it.

Using the ratio method given in the "Introductory," calculate the candle power of the unknown lamp, placing the calculated results at the top of the right-hand page.

Calculated Results

Average Distance of Standard	Average Distance of Unknown	$\left(\text{Standard Distance}\right)^2$	$\left(\text{Unknown Distance}\right)^2$
-----	-----	-----	-----

Candle power determined for unknown ....

Discussion:

Demonstrate the relation between the distance and the intensity of illumination.

How would you determine the candle power of a lantern?

Conclusion:

The candle power of lamp No._______ is______.

EXPERIMENT 37 (Alternative)

Measurement of Candle Power

OBJECT. To determine the candle power of a lamp by means of the Rumford photometer.

APPARATUS. Ring stand; vertical screen; meter stick; 2 incandescent lamps, one of known candle power. If electricity is not available, a standard candle and an oil lamp may be used. The ordinary paraffine candle "6's" or "12's" are about 1.25 candle power. A small lantern is a very desirable form of the oil lamp for this experiment on account of its candle power and its safety for laboratory use.

Introductory:

A 16 candle power lamp is one which gives 16 times as much light as one standard candle. If a candle and a lamp are both placed on the same side of a rod, they will each cast a shadow of the rod on a screen placed behind it. Each will then illuminate the shadow cast by the other. If the shadows are equally dark, then the screen receives the same intensity of illumination from both lights. The greater candle power of the incandescent

lamp, however, permits it to be much farther from the screen than the candle. If the latter is 20 m. from the screen, then the distance of the lamp will be found to be 80 m.

It is interesting to note that the square of these distances from the screen have the same ratio as the relative candle power of the two lights:

Illuminating Power of Candle		Illuminating Power of Lamp		Square of Candle Distance from Screen		Square of Lamp Distance from Screen
1	:	16	::	400	:	6400

Hence the ratio of the illuminating power of the two lights equals the ratio of the squares of their respective distances from the equally illuminated screen.

The photometer which determines candle power by means of shadows cast upon an opaque screen is the Rumford photometer.

Experimental:

1. Place the upright rod of the ring stand about 10 cm. from the vertical screen.

2. Place the lamp whose candle power is to be determined at a distance of about 120 cm. from the screen.

3. Place the standard lamp (or candle) in such a position that the two shadows of the rod formed on the screen shall be of the same intensity. These shadows should be near each other, but should not overlap.

Measure with the meter stick the distance of the standard lamp to the *nearer* of the two shadows, and the distance from the unknown lamp to the other shadow. Record the results in tabular form near the top of the left-hand page. *Why was the distance measured in each case to the nearer of the two shadows?*

4. Repeat the above test with the unknown lamp (or candle) successively at 100 cm. and 80 cm. from the screen.

In case two incandescent lamps are compared, their sockets should be connected to the same current outlet.

Observations

Number of Trial	Distance of Unknown from Screen	Distance of Standard from Screen
1	cm.	cm.
2	cm.	cm.
3	cm.	cm.

Candle power of standard ....

Make a drawing showing the essential parts of the photometer, and describe how you used it.

Using the ratio method given in the "Introductory," calculate the candle power of the unknown lamp, placing the calculated results in tabular form at the top of the right-hand page.

Calculated Results

Number of Trial	$\left(\text{Standard Distance}\right)^2$	$\left(\text{Unknown Distance}\right)^2$	Candle Power of Unknown
1			
2			
3			
Average	—	—	

Discussion:

Demonstrate the relation between the distance and the intensity of illumination.

Conclusion:

The candle power of ________________________ is _____.
(name lamp)

EXPERIMENT 38

Law of Reflection of Light

OBJECT. To determine the relation between the angle of incidence and the angle of reflection.

APPARATUS. Glass or metal mirror; clamp or block for holding mirror; sheet of clear glass the same size as the mirror; pins; ruler; protractor.

Introductory:

When sunlight falls upon a mirror, the light is reflected in a definite direction. The relation between the direction of the light before and after it strikes the mirror is stated in the law of reflection. We can locate a particular reflected ray by sighting along a ruler at the image of the object that is reflected. A line drawn along the edge of the ruler will mark the direction of the *reflected ray.*

Experimental:

(1) Draw a line across the middle of the right-hand page of your note-book. Mark it *MM.* Place the mirror perpendicular to the page with its reflecting surface on this line. Stick a pin upright in the page in front of the mirror and mark its position *P*.

(2) Placing the head on the level of the page and opposite one of the lower corners of the book, sight along a ruler placed on the page at the image of the pin, as seen in the mirror. When the edge of the ruler is exactly in

a line with the image of the pin, draw a line along the edge of the ruler.

(3) Repeat the operations described in (2), with the eye near the other lower corner of the book.

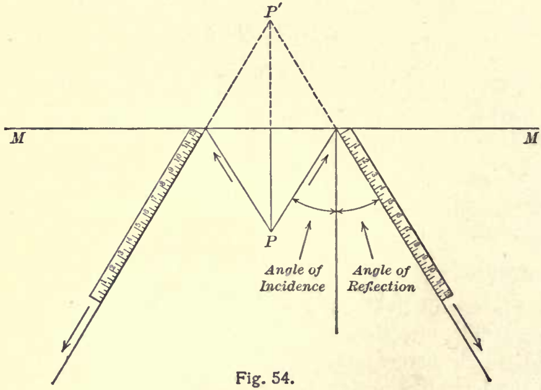

Fig. 54.

(4) Remove the mirror and substitute a transparent sheet of glass, carefully placing its *front* edge on the line *MM.* Protect the page behind the mirror from the direct light of the windows. Looking through this transparent mirror, insert a pin to coincide with the image of *P*. Mark the position of this pin *P'*. Remove the mirror and pins.

(5) Continue each of the lines drawn along the edge of the ruler as solid lines to the mirror line *MM*, and continue them as dotted lines behind the mirror until they meet. *Do these solid lines represent incident or reflected rays?*

From *P* draw a line to the intersection of each of the lines just drawn with the mirror line. *Do these lines from*

P mark incident or reflected rays? Connect P and P' with a line, solid from P to the mirror and dotted from the mirror to P'. Mark the direction in which light is passing along each of the solid lines by an arrow on that line.

(6) At the intersection of one of the solid lines with the mirror line, erect a perpendicular to the mirror line. The angle between the line coming from the pin to the mirror and this perpendicular line is called the *angle of incidence.* The angle between the reflected ray and this perpendicular is called the *angle of reflection.* Measure these angles with a protractor.

Record in tabular form near the top of the left-hand page the measurements called for.

OBSERVATIONS

Angle of incidence	°
Angle of reflection	°
Distance of pin from mirror	*cm.*
Distance of image from mirror	*cm.*
Angle between MM and PP'	°

A simple sketch of the apparatus as seen from above should be made and the experimental operations described briefly.

Discussion:

Answer the italicized questions occurring in the experimental directions. As seen in the mirror, from what point do the rays sighted along the ruler appear to come? From what point do they actually come?

Compare the distance of the image of the pin as seen in the mirror with the distance of the pin itself.

Conclusion:

State the relation between the angle of incidence and the angle of reflection.

EXPERIMENT 39

Images in a Plane Mirror

OBJECT. To compare an object with its image in a plane mirror with respect to size, distance, and form.

APPARATUS. Glass plate for mirror; wooden block with slot for holding mirror in vertical position; half-meter stick, or foot ruler; pins.

Introductory:

The plane mirrors which hang on our walls give rise to some interesting questions. Why does your image in the mirror seem to approach you as you walk toward the mirror? Why do you sometimes move your hand in the wrong direction when attempting to adjust something on your head? Why is a long mirror desirable when you want to see your apparel from head to foot? An answer to these questions will be found in the study of the relations of the object to the image in a plane mirror.

The image of an object is composed of the images of the points in that object. We can locate the image of each point in a transparent mirror by direct observation, as was shown in the experiment on the law of reflection.

Experimental:

Draw a line across the middle of the right-hand page of your note-book. About two inches below this line of reference make a drawing of a quadrilateral set obliquely to the line, no side of the drawing to be less than $1\frac{1}{2}$ inches in length. Number the corners 1, 2, 3, and 4, as in Fig. 55.

Place the front of the glass plate along the line of reference. Place a pin at point 1 of your drawing and

set a second pin at the image of 1 as seen in the mirror. Mark the position of the image pin with a pencil dot and the figure 1′. Locate and mark the image of each corner in the same way. Connect these points by lines representing the images of the corresponding edges of the block.

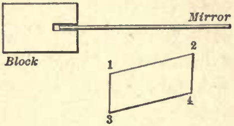

Fig. 55.

Shading the part of the notebook behind the mirror helps to secure a clear image in the mirror.

Compare the object and the image by means of the following measurements, which should be recorded in tabular form near the top of the left-hand page.

Observations

			Lines 3–4	Lines 1–3
Length of lines in object			-----	-----
Length of lines in image			-----	-----
Points	1	2	3	4
Distance of object's points from mirror	-----	-----	-----	-----
Points	1′	2′	3′	4′
Distance of image's points from mirror	-----	-----	-----	-----

Write a brief description of the method of the experiment on the left-hand page.

Conclusion:

On the second right-hand page, answer the following questions, using a complete sentence for each answer.

1. What relation exists between the object distance and the image distance of a point from the mirror line?

2. Compare the size of the object and its image.

3. Is the image formed by a vertical mirror erect or inverted? (Before answering, consider your own image in a mirror.) Is the image of the pin in front of the mirror or behind it?

4. In which direction do the hands of a watch appear to turn when viewed in a mirror?

5. Are an object and its image in a plane mirror similar or symmetrical?

EXPERIMENT 40

Reflection in a Concave Mirror

OBJECT. To study the form and location of the images formed by a concave mirror.

APPARATUS. Concave spherical mirror of glass or metal, supported in a vertical position; two meter sticks so placed as to form a V with its apex beneath the center of the mirror; two screens mounted so as to slide on the meter sticks — one screen is opaque and the other has cut in it a round or square window, over which is pasted very thin paper, with ink lines ruled across it at right angles and an ink mark in one of the four spaces formed by the intersecting lines; candle or incandescent lamp, to be placed behind the translucent window.

Introductory:

The beam of light from a headlight, where the burner is quite near the surface of a concave reflector, is shaped like a cone with its apex behind the reflector. The beam from a searchlight may take a conical shape like that from the reflector. It may, however, be made parallel, or it may even be brought to a brilliant focus at some point in front of the searchlight. These changes in the shape of the beam are possible because the distance between the light and its

concave reflector can be varied. The position of the light when the reflected rays are parallel is called the *principal focus* and the perpendicular distance from the principal focus to the mirror is the *focal length* of the mirror. For every case of reflection from a concave mirror a definite relation exists between the distance of the object, the distance of its reflected image, and the focal length of the mirror.

Experimental:

(*a*) In a darkened room, the translucent screen, lighted from behind, is placed on one of the meter sticks at a considerable distance from the mirror. The opaque screen, on the other meter stick, is then moved backward and forward until a position is found where the most distinct image

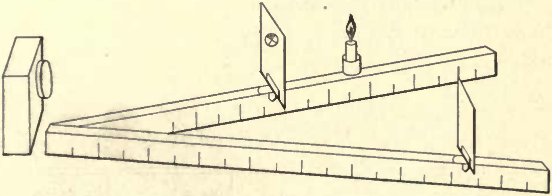

Fig. 56.

of the lighted window is formed. Record the distance of each screen from the mirror, also whether the image is larger or smaller than the object and whether the image is erect or inverted. Note in this and in each of the following cases whether there is any image back of the mirror, as in the case of the plane mirror.

(*b*) Find another pair of positions for the screens where the image will now be larger than the object, if it was smaller before, or *vice versa.* The same items are to be recorded as before.

(*c*) Another pair of positions is to be found where the image will be as nearly as possible the same size as the object, and a similar record made.

(*d*) The lighted window is next moved toward the mirror, until there is no image formed on the opaque screen at any distance, but an image appears to be formed behind the mirror. The position of the lighted screen and the general location and character of the image are to be recorded.

(*e*) Finally the illuminated screen is removed, and the meter stick on which this screen rests is pointed through the window at some distant object outside. If the weather permits, the window should be open. The location of the image should be recorded. This image is at the *principal focus* of the mirror.

All observations should be recorded in a table near the top of the left-hand page. Where distances are not measured, record general position of object or image.

Observations

Trial	Object Distance	Image Distance	Image Erect or Inverted	Image Enlarged or Diminished
a	cm.	cm.		
b	cm.	cm.		
c	cm.	cm.		
d	cm.	cm.		
e	cm.	cm.		

Make a simple outline drawing of your apparatus. A view from above, showing the location of the mirror, screens, and meter sticks, will be sufficient. Describe briefly your observations, stating particularly anything

you observe about the images which is not recorded in the table above.

For cases (*a*), (*b*), and (*c*), calculate, *as decimals*, the reciprocals of the object distance and of the image distance.

From (*e*) calculate the reciprocal of the principal focal length. This is to be compared in each case with the sum of the other two reciprocals. All results are to be recorded in tabular form at the top of the right-hand page.

CALCULATED RESULTS

Trial	$\frac{1}{\text{Object Dist.}}$	$\frac{1}{\text{Image Dist.}}$	$\frac{1}{\text{Object Dist.}} + \frac{1}{\text{Image Dist.}}$	$\frac{1}{\text{Focal Length}}$
a				
b				
c				

Discussion:

(1) When an object is at the *center of curvature* of a concave mirror (that is, at the center of the sphere from which the mirror is cut), the image is at the same place and of the same size as the object. Do any of your readings give you the radius of the curvature of your mirror? If so, which trial?

(2) When the object is at a distance greater than the radius of curvature, describe the image as to whether it is real or virtual, erect or inverted, enlarged or diminished. State the location of the image with reference to the center of curvature and to the principal focus.

(3) "When the object is between the center of curvature and the principal focus, the image is . . ." (Complete the statement, touching on each of the points noted in (2).)

(4) "When the object is between the principal focus

and the mirror, the image is . . . " (Complete as in (2) and (3).)

(5) What kind of rays are reflected to the principal focus? Where must an object be to send rays of approximately this character?

Conclusion:

What is the relation between the reciprocal of the focal length of a concave mirror and the sum of the reciprocals of the object distance and the image distance? Give your answer both in words and in an algebraic form.

EXPERIMENT 41

Reflection in a Convex Mirror

OBJECT. **To study the form and location of the images formed by a convex mirror.**

APPARATUS. Convex spherical mirror, mounted in a vertical position; candle or incandescent lamp; meter stick, with sliding opaque screen mounted on it.

Introductory:

A polished door knob reflects a distorted image of the objects in the room. Other bulging curved surfaces reflect in a similar manner. Convex spherical mirrors are frequently used as pocket mirrors.

Experimental:

Place the candle or lamp in a considerable number of positions, at different distances from the mirror. At each position, observe the character and location of the image

formed. As the object approaches the mirror, notice whether the image approaches or recedes.

Make a simple sketch of the apparatus and give a brief description of your work; a tabulation of observations and results is not necessary, as these are to be summed up in the Conclusion.

Conclusion:

Make a general statement as to the character (real or virtual), position (erect or inverted), shape (similar to object or symmetrical with it), and location of the images formed by a convex mirror.

EXPERIMENT 42

Refraction through a Glass Plate[1]

OBJECT. To study the refraction of a ray of light through a thick, rectangular glass plate.

APPARATUS. Thick rectangular glass plate; ruler; pins.

Introductory:

When we look through a thick plate of glass, objects seem displaced to one side or the other. This is the effect of refraction. We may study this effect by marking the path of an oblique ray with two pins before it enters the plate, and then sight along a ruler to determine the emergent ray.

[1] *Note to Instructor.* If a qualitative treatment of refraction is desired, students should perform Experiment 42 or Experiment 43, or both. The quantitative treatment, as well as the qualitative, is provided for in Experiment 44.

Experimental:

Place a rectangular plate of glass near the center of the right-hand page of your note-book, having two clear edges parallel to the top and bottom of the book. With a sharp, hard pencil, trace the outline of the plate of glass on the page.

Near a corner of the upper edge, draw a line at an angle to the upper edge of the glass. On this line place two pins, several centimeters apart. Place the eye on a level with the glass plate. Looking through the glass, place a ruler between the block and your eye, so that you can sight along its edge at the other two pins, as seen through the glass. Trace the position of the edge of the ruler.

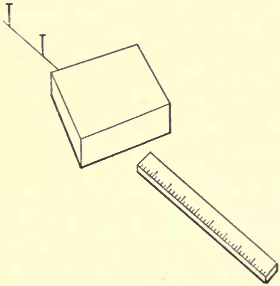

Fig. 57.

Remove the glass and pins. Continue the lines you have drawn until they have met the lines indicating the surfaces of the plate. Draw a line representing the path of the light through the glass, indicating by arrowheads on all lines, the direction in which the light is proceeding.

On the diagram, at the point where the ray of light entered the glass, draw a dotted line perpendicular to the surface of the plate, and continue it part way across the rectangle representing the plate.

At the point where the light ray emerged, draw a similar dotted perpendicular and continue it upward into the rectangle. These perpendiculars, drawn where the light

ray enters or emerges from the plate, are known as *normals.*

Write a brief description of the method of the experiment, referring to the diagram. No other drawing is necessary.

Conclusion:

Make a general statement regarding the relative direction of the entering and emerging rays, when the faces at which the light enters and emerges from the medium are parallel.

A ray of light on passing from a rarer to a denser medium is bent ----- the normal; in passing from a denser to a rarer medium, the ray is bent ----- the normal.

EXPERIMENT 43

Refraction through a Prism

OBJECT. To study the refraction of a ray of light passing through a triangular glass prism.

APPARATUS. Triangular glass prism, about 7 cm. on a side and 1 cm. thick; ruler; pins.

Introductory:

Glass prisms at one time were hung as ornaments in front of windows. Objects outside, when viewed through a prism, seem displaced to one side or the other. This is the effect of refraction. We may study the effect of refraction by marking the path of an oblique ray with two pins before it enters the prism, and then, sighting along a ruler, determine the emergent ray.

Experimental:

Place a triangular glass prism near the center of the right-hand page of your note-book, having one edge of the prism parallel to the bottom of the page. Trace the outline of the prism on the page with a sharp, hard lead pencil.

A little to the right of the center of the left edge of the prism draw a line at an angle to the edge. Do not make the angle between the ray and the edge more than 45°, or total reflection may occur. On the line just drawn, place two pins several centimeters apart.

Place the eye on a level with the glass prism. Looking through the glass, place a ruler between the prism and your eye, so that you can sight along its edge at the two pins as seen through the right side of the glass. The ruler should be moved until the two pins, as seen through the glass, appear in the same straight line. Trace the position of the edge of the ruler on the page.

Remove the glass and the pins. Continue the lines you have drawn to the lines representing the right-hand edge and the left-hand edge of the prism respectively. Draw a line representing the path of the light through the glass, indicating by arrow-heads on all lines the direction in which the light is proceeding.

On the diagram, at the point where the light entered the glass, erect a dotted line perpendicular to the surface of the glass, and continue it part way across the triangle representing the prism.

At the point where the light emerged, draw a similar dotted perpendicular, and continue it into the triangle.

These perpendiculars drawn where the light ray enters or emerges from the prism are called *normals*. Note the direction of bending of the light with reference to the normals at each surface of the glass.

A brief description of the method of tracing the ray through the glass should be written, but no drawing other than the diagram is necessary.

Discussion:

How is a ray of light bent with regard to the normal: (*a*) on entering a denser medium? (*b*) on emerging into a rarer medium?

Conclusion:

Is light bent by a triangular prism toward the apex (refracting angle) or toward the base of the prism?

EXPERIMENT 44

Index of Refraction

OBJECT. **To determine the index of refraction of glass.**

APPARATUS. Thick rectangular glass plate, or triangular glass prism (1 cm. thick) or both; pins; metric ruler.

Introductory:

When viewed through a thick plate of glass, objects seem displaced to one side or the other. This is the effect of refraction. This effect may be studied by marking the path of an oblique ray with two pins before it enters the plate, and then sighting along a ruler to determine the emergent ray.

Light travels faster in air than in a denser medium like glass. The ratio of the velocity of light in air to the velocity of light in glass is termed the index of refraction of air to glass. This ratio is mathematically equal to the ratio of the sine of the angle of incidence (air to glass)

to the sine of the angle of refraction. In this experiment you will learn what is meant by the angle of incidence and the angle of refraction. You will construct and measure the sine of each of these angles. You can then calculate the index of refraction of glass, relative to air.

Experimental:

If a rectangular glass plate is used, follow the experimental directions given in Experiment 42, page 150. For a triangular prism, follow Experiment 43, page 152. Then complete the experiment according to the directions which follow.

At the point where the light ray enters and the point where it emerges from the glass, perpendiculars to the glass surface (normals) have been erected. Indicate the angles between the incident rays and the normals as angles of incidence; those between the refracted rays and the normals as angles of refraction. Taking each intersection of a normal with the surface of the glass as a center, describe circles of as large radius as possible, without the circles intersecting. From the intersection of each ray with its circle, drop a perpendicular to the normal in that circle. This perpendicular is known as the *sine* of the angle of incidence or of the angle of refraction, as the case may be.

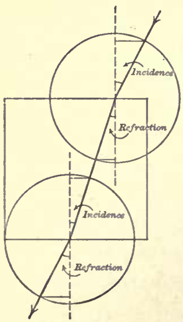

Fig. 58.

With a metric scale determine the lengths of these sines and record near the top of the left-hand page in a tabular form like the following:

Observations

Sine of first angle of incidence	*cm.*
Sine of first angle of refraction	*cm.*
Sine of second angle of incidence	*cm.*
Sine of second angle of refraction	*cm.*

Give a brief account of the geometrical construction you have made. No further drawing is necessary.

Calculate the index of refraction from air to glass, making use of the measurements made on each side of the glass; in each case the index is the ratio between the sine of the air angle and the sine of the glass angle. Tabulate the results.

Calculated Results

	First Case	Second Case	Average
Index of Refraction			

Conclusion:

The index of refraction of glass, relative to air is-----

EXPERIMENT 45

Total Reflection

OBJECT. To observe total reflection and determine the critical angle for glass.

Apparatus. Flat triangular glass prism, about 7 cm. on a side and 1 cm. thick, having a fine line drawn across the center of one of the narrow faces, at right angles to the broad faces; 4 pins; ruler; protractor.

Introductory:

The surface of a glass of water, viewed obliquely from below through the water itself, becomes bright like a sil-

vered mirror, and reflects like one, when a certain position has been reached. Ice, so transparent when in a block, is white when powdered. Both of these appearances result from total reflection. Light passing through a dense medium, as water, ice, or glass, to the surface of a medium less dense, as air, is refracted away from the perpendicular. That is, the angle of refraction, under these circumstances, is always greater than the angle of incidence. When the angle of incidence reaches a certain value, the refracted ray will lie along the surface. This value of the angle of incidence is called the *critical angle*. If the angle of incidence increases to a value greater than the critical angle, the light is totally reflected, instead of being refracted. By finding experimentally the least angle of incidence at which total reflection takes place, the critical angle can be found, though the value obtained from this experiment is an approximate one only.

Experimental:

(*a*) A flat triangular prism of glass is placed on the center of the right-hand page of the note-book. The directions which follow must be fully understood before the experiment is begun and must be exactly followed to secure accurate results.

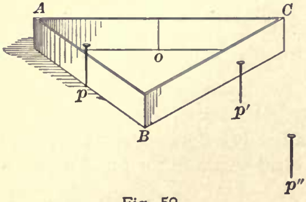

Fig. 59.

Close to the prism on the side AB insert a vertical pin (p) firmly in the paper. Near the center of the side AC a vertical line (o) is ruled on the glass. Placing the eye on the level of the book, move the head until, looking through the side BC, an image of the pin (p) is seen

reflected in AC. Note the appearance of AC when the head is in this position. The observed image is the result of the total reflection of light passing through the glass from (p) to the surface AC.

(*b*) Move the head sideways until the reflected image of the pin suddenly disappears. Continue moving the head in the same direction. Does the image again appear? Move the head in the opposite direction. Does the image now appear? Beyond the point where the image suddenly disappeared, the light rays from the pin were refracted in the ordinary way, and the pin might have been seen by looking through the side AC. The particular angle of incidence on the surface AC of rays from the pin at which total reflection begins and refraction ends, is called the *critical angle*. It is now to be determined.

(*c*) Keeping the side AB always closely against the pin, move the prism and the head into various positions, until the reflected image is just about to coincide with the vertical mark on AC as the image disappears. When you are sure that you have located this position correctly, insert two pins (p') and (p'') so they are in a straight line with the mark on AC, *as seen through the glass.* These pins, then, lie in the line taken by the reflected ray after it leaves the glass.

Holding the prism firmly to the paper with the left hand, trace its outline and mark on AC the exact location of the vertical mark (o) on that face. Removing the prism, draw a line from (p) to the marked point (o), representing the path of the ray incident at (o) from (p). Draw a line through the pins (p') and (p'') to BC, and from the point of intersection with BC draw a line to (o). Place an arrow head on each line to show the direction of the light in each case.

At (*o*) erect a perpendicular to *AC*. With a protractor measure the angle of incidence (which is the critical angle if your work has been done correctly) and the angle of reflection in the glass. Record the readings of the protractor on the figure.

If time permits, repeat the process of finding the critical angle, using the next page of the note-book.

No table of observations is necessary, as all observed results are recorded on the drawing. Write a brief but complete description of your work, referring to the drawing, and mention any conditions that were observed which are not shown by the drawing. No sketch of the apparatus is necessary.

Discussion:

Through what kind of a medium must light pass in order to be totally reflected at the transparent surface of that medium?

Under these circumstances, if the angle of incidence be greater than the critical angle, what happens to the light? If the angle of incidence is less than the critical angle, what happens?

In total reflection, how does the angle of incidence compare with the angle of reflection?

Conclusion:

The critical angle of glass is ------°.

EXPERIMENT 46 A

Study of a Converging Lens[1]

OBJECT. To locate the principal focus of a converging lens and to study the images formed by such a lens, when the lens is at different distances from the object.

APPARATUS. Double convex lens, 10 to 15 cm. focus; opaque screen; half-meter stick; screen with translucent window (see description under "Apparatus," page 166); meter stick, mounted as shown in Fig. 61; lens and screen holders to slide along the meter stick; incandescent lamp or other light; strip of paper more than twice the focal length of the lens.

Introductory:

Converging lenses are among the most useful parts of optical instruments, such as cameras, telescopes, and projection lanterns. The first experience of most boys with a converging lens is the handling of a "burning glass." The parallel rays from the far distant sun enter the lens, and are so bent in direction that they converge to a point. This point of convergence of parallel rays is the *principal focus* of the lens. The *focal length* of a lens is the distance from the lens to the principal focus.

When we look through a converging lens at an object, we see an image of the object. The relations of the object and image vary according to the position of the object with reference to the principal focus. The relations are not hard to find and are interesting, because they explain the use of the converging lens in some of its important practical applications.

[1] This experiment is essentially qualitative in its character. Experiments 46 B and 47 provide for a quantitative treatment of the convex lens. Either one kind of work or the other should be selected, as the performance of all three experiments would involve unnecessary repetition.

Experimental:

(I) *The Principal Focus.*—If we assume that the rays from a fairly distant object are practically parallel, and that these rays on entering the lens converge to the principal focus, the location of a sharp image of the distant object on a screen tells us the position of the principal focus. Accordingly, set the lens on one of the main divisions of a half-meter stick, and move the screen until the most distant bright object which can be seen through the window is sharply focused on the screen. Note the distance between the lens and the screen (principal focus). Record this focal length in the table of observations near the top of the left-hand page. Take two more readings, moving the lens and screen each time. Record these readings, and the average of the three, which will be considered the focal length. A simple and very convenient form of lens holder is shown in Fig. 60.

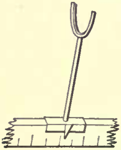

Fig. 60.

(II.) *Relations of Object and Image.*—On a strip of paper draw a line just twice the focal length of the lens in length; in the middle of the line place a mark, the distance of which from either end will be equal to the focal length. All distances in the remaining portion of the experiment are to be measured in terms of the focal length of the lens, by means of this marked line, and not by means of the numbers on the meter stick.

At one end of the meter stick place an incandescent lamp or other light, and directly in front of the light a screen with a translucent window in it to serve as an object (Fig. 61).

(*a*) Set the lens at its focal length from the illuminated screen. The object is now at the principal focus of the

lens. Move the opaque screen on the other side of the lens, and note whether or not an image is formed on this screen. The formation of an image means that the rays of light leaving the lens converge. If an image is not formed, the rays leaving the lens are either parallel or divergent. *When the object is at the principal focus, what is the direction of the rays leaving the lens?* (Recall the method of finding the principal focus.)

(*b*) Move the lens nearer the illuminated screen than in (*a*). The object is now within the principal focus. Move the screen to ascertain whether or not an image is

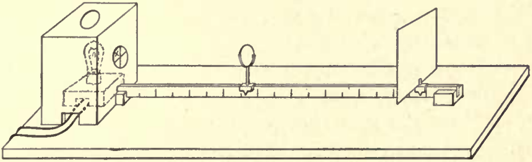

Fig. 61.

formed. Look through the lens at the illuminated screen and describe its appearance. *In this case what do you think is the direction of the rays leaving the lens? Explain.*

(*c*) Place the lens so that the object is at a distance of twice the focal length. Place the screen at an equal distance on the other side of the lens. Is the image on the screen erect or inverted?[1] Is it larger or smaller than the object? *When the object is at twice the focal length from the lens compare* (1) *the relative distances from the lens of object and image,* (2) *the relative size of object and image. At*

[1] In case a sharp image is not formed at twice the focal length, find the shortest distance between the object and the screen at which a distinct image of the object can be formed on the screen. Compare the object and image distances with each other and with twice the focal length.

what distance from a camera lens would you place a drawing in order to obtain a photographic copy of the same size?

(*d*) Move the lens in a little toward the object, so that it is at a distance from the object greater than the focal length, but less than twice the focal length. Move the opaque screen until a sharp image of the illuminated screen is obtained on it. Alongside the line already drawn on your strip of paper, lay off another line whose length is the distance between the lens and the image in this case. On this line also mark the object distance.

Compare the image distance with twice the focal length. Note the relative sizes of object and image. *When an object is at a distance from a lens greater than the focal length, and less than twice the focal length,* (1) *state the general location of the image in terms of the focal length,* (2) *compare the image and object as to size.*

(*e*) Move the lens to a point whose distance from the object is equal to the image distance obtained in (*d*). The object distance is now greater than twice the focal length. Slide the opaque screen into a position where a sharp image is formed. Note the relative sizes of object and image. Beside the line drawn in (*d*), lay off another line on which the object and image distance in this case are marked. Compare the image distance in this case with twice the focal length and with the focal length. *When an object is at a distance from a lens greater than twice the focal length,* (1) *state the general location of the image,* (2) *compare the object and image as to size.* Conjugate foci of a lens are points so located in reference to the lens that, if the object is placed at either point, the image will be located at the other. *State two cases of conjugate foci shown in this experiment.*

In a table near the top of the left-hand page, the readings of focal length are to be entered. Immediately

beneath this the strip of paper on which the various distances have been recorded, is to be pasted by one end. Each line on the strip should be marked to indicate just what distances it records.

OBSERVATIONS

	1	2	3	AVERAGE
Focal length of lens	_____*cm.*	_____*cm.*	_____*cm.*	_____*cm.*

A brief description of the work done in each part of the experiment should follow the "Observations." Any observations not recorded on the strip or in the table should be included in the description. The description should be accompanied by a drawing showing the apparatus when the principal focus was being determined, and a drawing showing the location of lens, screens, and lamp in position for one of the cases where an image was formed.

Discussion:

Answer under this heading all questions in italics contained in the experimental directions.

Where will the screen for a stereopticon be located with reference to the focal length of the objective lens? Where will the lantern slide be located?

Conclusion:

What is the least distance from a converging lens at which an object can be placed in order that a real image may be formed?

State a general relation between the sizes of the object and image, and their respective distances from the lens.

EXPERIMENT 46 B

Focal Length of a Converging Lens

OBJECT. To locate the principal focus and determine the focal length of a converging lens.

APPARATUS. Double convex lens, 10 to 15 cm. focus; lens holder; screen; screen holder; half-meter stick; the lens and screen holders should fit and slide along the half-meter stick.

Introductory:

A camera may be made which will take fairly sharp pictures of all objects more than 100 ft. or so away. This is because objects at a greater distance than that send practically parallel rays into the lens and so form the image at the *principal focus* of the lens. By assuming that the rays entering the lens from fairly distant objects do converge to the principal focus, we may locate the focus by getting the image of a distant building on a screen, which will then be at the principal focus. The *focal length* of a lens is the distance from the lens to the principal focus.

Experimental:

Set the lens on a half-meter stick and move the screen until the most distant bright object which can be seen through the window is sharply focused on the screen.

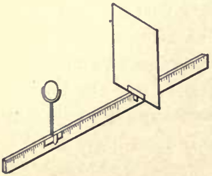

Fig. 62.

Take three readings, moving both lens and screen each time, recording in each case the position of the lens and the screen in the table of observations near the top of the left-hand page.

Observations

Trial	Position of Lens	Position of Screen	Number of Lens
1	-----	-----	-----
2	-----	-----	-----
3	-----	-----	-----

Make a drawing of the apparatus and show by short dash lines the path of the light rays before and after passing through the convex lens. Briefly describe the method of the experiment.

In the table of calculated results at the top of the right-hand page, record the average distance between the lens and the principal focus as the focal length.

If time permits, determine the focal length of a second lens, recording it in the last line of the table of calculated results.

Calculated Results

	Trial 1	2	3
Distance between lens and screen . .	-----	-----	-----
Focal length of lens No. ----- (*Average of* 1, 2, & 3)			-----
Focal length of lens No. -----			-----

Discussion:

Define (*a*) the principal focus, (*b*) the principal focal length. Why is the most distant object available selected? Why is the convex lens spoken of as a converging lens?

Conclusion:

The principal focal length of lens No. ------ is ------.

EXPERIMENT 47

Conjugate Foci of a Converging Lens

OBJECT. **To determine the conjugate foci of a converging lens and their relation to the principal focus.**

APPARATUS. Double convex lens (10 to 15 cm. focal length); lens holder; opaque screen; screen holder; meter stick, supported in the slots of two wooden blocks; opaque screen, with round or square window cut in it, over which is pasted a piece of very thin paper with ink lines ruled across it at right angles, and with an ink mark in one of the four spaces formed by the intersecting lines; candle or incandescent lamp to be placed behind the translucent window (see Fig. 61, page 161).

Introductory:

When a pencil of light diverges from a point and is incident on a lens, it is brought to a focus by the lens at a point on the axis passing through the radiant point from which the light came. The radiant point and the focal point are conjugate foci of the lens. *Conjugate foci* of a lens are points so located with reference to the lens that, if the object is placed at either point, the image will be located at the other.

Conjugate foci may be located by determining the two positions between an object and a screen where a lens may be placed so as to form a sharp image on the screen. In such positions, an important relation exists between the distance of the object from the lens, the distance of the image from the lens, and the focal length of the lens.

Experimental:

Arrange the apparatus as in Fig. 61. Then adjust the position of the lens so that a distinct image of the illuminated paper will be formed on the opaque screen. Is the image erect or inverted? Real or virtual?

Measure the diameter of the object and of the image. Record in tabular form near the top of the left-hand page.

Record the position on the meter stick of the object, the lens, and the image.

Leaving the object and screen in position, move the lens until you find another position for it, at which the lens will again produce a distinct image. Make the same observations as before, and record.

OBSERVATIONS

	I	II
Position of object	----- cm.	----- cm.
Position of lens	----- cm.	----- cm.
Position of image	----- cm.	----- cm.
Diameter of object	----- cm.	----- cm.
Diameter of image	----- cm.	----- cm.
Image—erect or inverted . . .	-----	-----
Image—real or virtual . . .	-----	-----
Number of lens	-----	-----

Make a simple drawing, showing the arrangement of apparatus, and describe how it was used.

In case you do not know the focal length of the lens, determine it by the method given in Experiment 46 B, on page 164.

Place the table for the calculated results at the top of the right-hand page, and make the calculations indicated. All reciprocals should be worked out as decimals, the result being carried to four decimal places.

Calculated Results

	I	II
Distance of object from lens . .	----- *cm.*	----- *cm.*
Distance of image from lens . .	----- *cm.*	----- *cm.*
$\frac{1}{\textit{Object distance}}$	-----	-----
$\frac{1}{\textit{Image distance}}$	-----	-----
$\frac{1}{\textit{Object distance}} + \frac{1}{\textit{Image distance}}$	-----	-----
Principal focal length of lens . .	-----	----- *cm.*
$\frac{1}{\textit{Focal length of lens}}$	-----	------

Discussion:

What is the relation between the diameters of the object and the image, and their respective distances from the lens?

Conclusion:

Compare the sum of the reciprocals of the image and object distances with the reciprocal of the principal focal length.

EXPERIMENT 48

Magnifying Power of a Lens

OBJECT. To find the ratio of the diameter of an object viewed with the unaided eye to the diameter of the image seen through a converging lens.

APPARATUS. Two double convex lenses, of 5 and 10 cm. focal length respectively; half-meter stick; opaque screen; lens holder and screen holder to slide along the meter stick; piece of cardboard, $2'' \times 3''$, covered on one side with black paper, and with a square hole in the center 1 cm. on a side; paper metric scale; ring stand with two small condenser or burette clamps, with cork-lined jaws.

Introductory:

Double convex lenses are used in certain optical instruments because the images produced by them are larger than the objects viewed. The ratio of the diameter of the image to the diameter of the object is the magnifying power of the lens.

By the size of an object, we mean that apparent to the unaided eye. It has been found, however, that the majority of people obtain the most distinct vision when the object is 25 cm. from the eye. Accordingly, if we take for our object a line, it should be viewed at the *distance of most distinct vision* (25 cm.). This line will appear longer when seen through a converging lens. The ratio of the apparent length of the line as seen through the lens to the length of the line seen with the unaided eye, is the magnifying power of the lens. In this manner we are comparing the diameter of an object with that of its image.

Experimental:

(*a*) Set the lens of greater focal length on some even centimeter division of the half-meter stick pointing toward the window. On the other end of the stick place the screen, and move it toward the lens until the most distant bright object which can be seen through the window is sharply focused on the screen. Note the distance between the lens and the screen (principal focal length). Record this focal length in the table of observations placed near the top of the left-hand page.

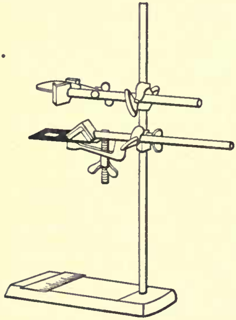

Fig. 63.

Place the lens horizontally (Fig. 63) in the jaws of a clamp on a ring stand, tightening the clamp just enough to hold the lens, but not enough to crack the glass. Adjust the clamp in height so that the lens is 25 cm. above the table top.

Support with another clamp the cardboard diaphragm, so that its square opening is just at the principal focus of the lens. Place a paper metric scale on the table below the opening.

Look down through the lens at the scale with one eye, while viewing the scale at the same time with the other (unaided) eye. Note how many millimeter divisions seen with the unaided eye are apparently covered by the width of the opening. A little practice will enable you to make the comparison without any straining of the eyes.

Record the apparent width in millimeters in the table of observations. Measure in millimeters the actual width of the opening, and record. This actual width is the num-

ber of millimeter divisions which the unaided eye could see through the square opening if it were placed upon the scale.

(*b*) Repeat the measurements of part (*a*), using the lens of shorter focal length.

Observations

Width of opening in diaphragm . . . ------ *mm.*

	Part (*a*)	Part (*b*)
Focal length of lens . . .	------ *cm.*	------ *cm.*
Apparent width of opening seen through lens . . .	------ *mm.*	------ *mm.*

Make a drawing showing the relative position of the eyes, the lens, the opening in the diaphragm, and the metric scale when the comparison was made. Describe the method of making the comparison.

The ratio between the number of millimeter divisions which can apparently be seen through the opening when the lens is used, and the number of such divisions visible through the opening to the unaided eye, is the magnifying power of the lens. Calculate the magnifying power of the lenses used in (*a*) and (*b*). Record your results in the table of calculated results at the top of the right-hand page.

Calculated Results

Magnifying power of lens in (*a*) . . . ------ *times*
Magnifying power of lens in (*b*) . . . ------ *times*

Discussion:

Why is the metric scale viewed at a distance of 25 cm.? Is the lens of shorter focal length more desirable for a simple magnifier than that of longer focal length? Explain.

Conclusion:

Complete the statement:

The magnifying power of a lens is the ratio of ---------

EXPERIMENT 49 A[1]

The Astronomical Telescope

OBJECT. (*a*) To construct and learn the operation of a simple astronomical telescope; (*b*) to find its magnifying power.

APPARATUS. Double convex lens of short focal length (5 or 10 cm.); lens holder to slide along half-meter stick; lens of long focal length, not over 40 cm. (a reading glass may be used); holder or clamp for supporting lens; cardboard screen with translucent window 1″ square; screen holder to slide along half-meter stick; half-meter stick; ring stand; burette clamp; strip of white cardboard, 20″ x 3″, ruled with black vertical lines 1″ apart and $\frac{1}{8}$″ thick; strip of white cardboard, about 5″ x 2″, with a black arrow 2″ or 3″ long drawn along the middle.

Introductory:

An astronomical telescope in its simplest form consists of two double convex lenses at the opposite ends of an opaque tube, with some device for varying the length of the tube. The lens through which the eye looks is generally smaller than the lens at the end of the tube pointing towards the object to be viewed. These two lenses, moreover, will be found to differ considerably in focal length.

[1] Experiments 49 A and 49 B are similar in method and afford similar training. It is recommended that only one of them be performed, unless there is abundant laboratory time.

To understand the operation of an astronomical telescope, we must find why two lenses are used; why the lenses must be so different in focal length; what is meant by bringing the instrument into focus. The first step toward answering these questions is to determine the focal length of each lens. Then by mounting them in suitable relative positions, we can improvise a telescope and determine the principles of its operation.

Experimental:

(a) *Focal Length of the Lenses.*—Take the lens of short focal length, which is to be used as the eyepiece of the telescope, and mount it on the end of a half-meter stick pointing toward a window. Move a screen on the stick toward the lens, until the most distant bright object seen through the window is sharply focused on the screen. Is the image erect or inverted? Measure on the half-meter stick the distance between the lens and the screen. Record this focal length in a table of observations near the top of the left-hand page.

Mount the other lens (the objective) over one end of the half-meter stick, by means of the clamps and ring stand, and determine its focal length in a similar manner, and record.

(b) *Use of the Lenses.*—Leaving the objective focused on the screen, mount the eyepiece on the meter stick, on the other side of the screen, so that the centers of the two lenses are on the same horizontal line. (Fig. 64.)

Looking through the eyepiece, move it along the stick until you can see distinctly the image thrown on the screen by the objective. Record the distance of the *eyepiece* from the screen. Does the image viewed through the eyepiece appear larger or smaller than the image that the unaided eye can see on the screen?

Leaving the lenses undisturbed, remove the screen. Again look through the eyepiece. Can you see the image of the distant object? Record the distance between the objective and the eyepiece.

(*c*) *Focusing.* — Shift the meter stick in the clamp a few centimeters. Move the eyepiece until you can see distinctly through it the image of the distant object. This is the method of focusing the eyepiece of a telescope on the image of a distant object projected through the objective. Record the distance between the objective and the eyepiece.

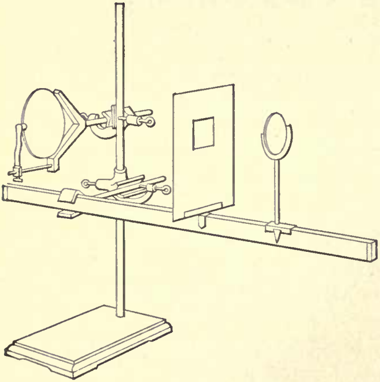

Fig. 64.

(*d*) *Magnifying Power.* — On the most convenient and distant wall of the room, place as an object, a black arrow on a strip of white cardboard. The arrow should be in the same horizontal plane as the centers of the lenses of the telescope.

Focus the telescope on the black arrow. Have another student stand at the distant wall and move the scale with the black ruled lines down toward the arrow while you are looking through the telescope. By using both eyes at the same time, you will be able to see how many divisions of the scale are equal to the apparent length of the arrow, as seen through the telescope. Measure the real

length of the arrow in divisions of the ruled scale. Record both measurements in the table of observations. How many times is the length of the arrow magnified by the telescope? Record this magnifying power in the table of calculated results.

Observations

Part (a)	*Focal length of eyepiece* . . .	*cm.*
	Focal length of objective . . .	*cm.*
Part (b)	*Distance of eyepiece from screen* .	*cm.*
	Distance between objective and eyepiece	*cm.*
Part (c)	*Distance between objective and eyepiece*	*cm.*
Part (d)	*Actual length of arrow*	*divisions*
	Apparent length of arrow through telescope	*divisions*

Make a simple outline drawing, showing the arrangement of the lenses in your telescope. Describe briefly the steps you took in each part of the experiment.

Place the table of calculated results at the top of the right-hand page.

Calculated Results

Sum of focal lengths of objective and eyepiece	*cm.*
Magnifying power of telescope	*times*
Ratio of focal length of objective to focal length of eyepiece	$\frac{\quad cm.}{\quad cm.} = \frac{\quad}{1}$

Discussion:

Why is a lens of long focal length used as the objective of an astronomical telescope? What is the purpose of the eyepiece (the lens of short focal length)? Compare the

observed magnifying power with the ratio of the focal lengths.

Conclusion:

Complete this statement:

When an astronomical telescope is focused on a distant object, the distance between the objective and the eyepiece is equal to the --

----

EXPERIMENT 49 B

The Compound Microscope

OBJECT. To construct a compound microscope and to determine its magnifying power.

APPARATUS. Two double convex lenses of short focal length (about 5 cm.); lens holder and screen holder, to slide along a half-meter stick; half-meter stick; piece of cardboard, with a black arrow 1 cm. in length drawn on the middle of one side; ring stand with two cork-lined burette or small condenser clamps; paper metric scale.

Introductory:

The compound microscope in its simplest form consists of two converging lenses of short focal length, mounted a suitable distance apart and usually at the ends of an opaque tube. The objects viewed with the microscope are small ones and they are placed under the lens known as the *objective* and just beyond its principal focus. The image formed by the objective is viewed through the other lens (the *eyepiece*). The magnifying power depends on the focal lengths of the two lenses used and also on the distance between them.

The magnifying power may be defined as the ratio between the diameter of the image seen through the microscope and the diameter of the object viewed with the unaided eye. We shall view a little ruled arrow through the microscope, while the other eye is looking at a metric scale placed beside the arrow.

Experimental:

(*a*) *Focal Length of the Lenses.* — Take one of the lenses for the eyepiece and mount it on a half-meter stick near the end pointing toward a window. Move a screen on the meter stick toward the lens until the most distant bright object to be seen through the window is sharply focused on the screen. Then measure on the meter stick the distance between the lens and the screen. Record this focal length in the table of observations near the top of the left-hand page.

Determine similarly the focal length of the other lens (the objective) and record the distance in the table.

(*b*) *Construction.* — Place on the base of the ring stand a piece of white cardboard with its drawing of a little arrow for the object.

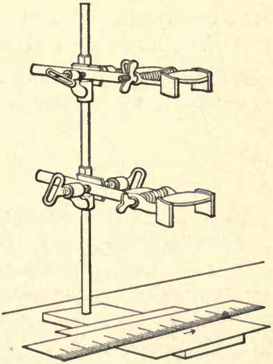

Fig. 65.

Carefully mount each of the lenses in the cork-lined jaws of a small clamp and arrange on the ring stand as shown in Fig. 65. The objective should be fixed above the object at a height greater than the focal length of that lens, but at less than twice the focal length.

Looking through the eyepiece, move that lens up and down until a sharply defined, black image of the little arrow is seen. Is the image real or virtual? In what two respects is the image different from the object? Measure the height of the objective above the object and the vertical distance between the centers of the two lenses. Record these distances in the table. Leave the microscope focused for part (*c*).

(*c*) *Magnifying Power.* — Place a paper metric scale near the little arrow and parallel to it. With one eye look through the microscope at the arrow, while, at the same time, with the other (unaided) eye you are viewing the metric scale. Slide the metric scale so that you can measure the length of the arrow, as it appears through the microscope. The divisions of the scale should not look magnified. Record the apparent length of the arrow in millimeters. Measure the actual length of the arrow with the scale and record it in the table. What is the apparent magnifying power of your microscope?

Observations

Focal length of the eyepiece	*cm.*
Focal length of the objective	*cm.*
Distance of objective from object	*cm.*
Distance between centers of lenses when microscope is focused	*cm.*
Characteristics of image (enlarged or diminished)	
Characteristics of image (erect or inverted) .	
Apparent length of arrow through microscope .	*mm.*
Actual length of arrow	*mm.*

Make a simple diagram showing the relative positions of the eye, the two lenses, and the object. Describe,

with reference to the drawing, the work in (*b*). Describe also how you determined the magnification in (*c*).

Calculated Results

Magnifying power of microscope . . . . times.

Discussion:

Why should not the object be placed at the principal focus of the objective? When the object is beyond the principal focus, but not distant twice the focal length from the objective, how does the image compare in size with the object? Is this image real or virtual? Upon what is the eyepiece focused? Compare the distance between the lenses with the focal length of the eyepiece. Explain how this distance affects the magnifying power of the microscope.

Conclusion:

State the essentials in the construction of a compound microscope. How must the eyepiece and the objective be placed to secure magnification?

EXPERIMENT 50

Dispersion of Light by a Prism

OBJECT. To observe the effect of a triangular glass prism on a beam of white light.

APPARATUS. Triangular glass prism, 60°; opaque covering for the upper half of laboratory window, with a slit 6 in. × $\frac{3}{8}$ in.; second opaque covering, with $\frac{3}{8}''$ slits arranged as in Fig. 67.

Introductory:

When we look through glass prisms, such as are sometimes hung from the bottom of a lamp shade, we notice that

the outlines of objects show a fringe of color. When the sun begins to shine before the rain stops falling, a rainbow, consisting of a band of the same colors seen through the glass prism, appears in the sky. In both of these cases white light has been broken up into colors, by passing through a transparent medium more dense than air.

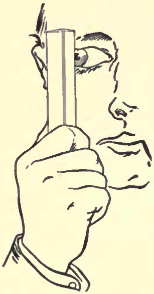

Fig. 66.

Experimental:

(*a*) The upper part of the laboratory window will have an opaque covering, in which a narrow slit has been cut. Take a position from which the sky can be seen through the slit. Close one eye and, holding the prism in front of the other with one edge pointing toward the slit, rotate the prism slowly until the slit appears as a band of color. Name the colors distinctly seen, in the order in which they appear to you. Since the different colors appear in different positions, what must be true of the amount of bending of each? Notice carefully the position of the faces of the prism and see if you can determine which of the colors is most refracted.

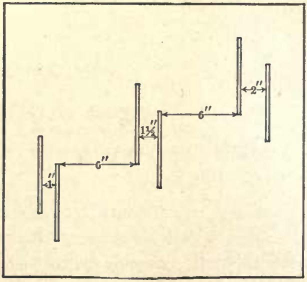

Fig. 67.

(*b*) On the upper half of another laboratory window there has been placed an opaque covering with three pairs of slits arranged as in Fig. 67. Holding the prism in front of

the eye as before, look at the slits. Note the overlapping of the spectra. Find a case in which there is visible a color not evident in the spectrum as seen in (*a*). What colors by their overlapping produced this new color? Can you find another distinct color formed by the combining of the light rays of two different colors? In which case do you find a streak of white produced by the overlapping spectra. What colors combined to form this whitish light?

Make one sketch showing how the prism was held in front of the eye, and two diagrams showing the arrangement of the slits on the opaque coverings. Describe the experiment with reference to these drawings, stating the results in each case. The description may be shortened by the use of further diagrams in which the colors of the spectra are mapped.

Conclusion:

What happens to a ray of white light in passing through a glass prism? How may other colors be formed from the primary colors of the solar spectrum?

EXPERIMENT 51

Fixed Points of a Thermometer

OBJECT. To test the boiling and the freezing points on a mercury thermometer.

APPARATUS. Steam boiler with bent glass delivery tube; 1-hole rubber stopper tightly fitting the top of the boiler chimney; hydrometer jar; thermometer, $-10°$ to $110°C.$; glass funnel; cylindrical or other jar to support funnel; burner; supply of cracked ice.

Introductory:

A long while ago it was noticed that when pure water was boiled at the top of a high mountain, it was not so hot as when pure water was boiled near the sea level. This is because the pressure of the air is less at the mountain top. The boiling point of pure water, under standard conditions of barometric pressure, is 100° C. We wish to test a thermometer to determine whether its 100° mark is correctly placed, and also to find its error, if any. We shall also test its zero graduation, which should mark the temperature of water in the process of freezing, or of ice in the process of melting.

Experimental:

Place the tabular form for observations near the top of the left-hand page. Record all readings as soon as made.

(*a*) *Freezing Point*. — Fill a funnel about half full of cracked ice and support it in a jar (Fig. 68). Insert the thermometer in such a way that the ice will be packed around the bulb and nearly to the zero of the scale.

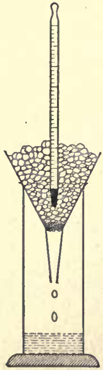

Fig. 68.

After the mercury has remained stationary for at least five minutes, take the reading of the thermometer to tenths of a degree. The difference between this reading and the zero of the scale is the freezing point *error* of the instrument. No allowance need be made for the atmospheric pressure.

State the *correction* for your thermometer as – or +, according as the freezing point was indicated too high or too low. This correction should be added algebraically to all readings near the freezing point taken with this thermometer.

(*b*) *Boiling Point.* — To test the boiling point of the thermometer, see that the chimney is on the boiler and the thermometer adjusted so that the 100° mark is just above the stopper. The upper tube of the boiler should be open; the lower one closed. The bulb of the thermometer should not dip into the water in the boiler, which is half filled with water. Boil the water until the reading of the thermometer remains stationary for at least two minutes. Then take a reading of the thermometer, estimating to tenths of a degree, and record.

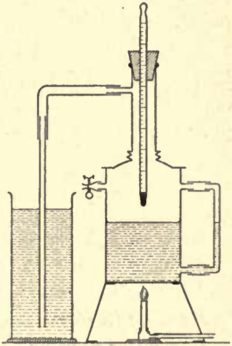

Fig. 69.

(*c*) Next determine the effect on the boiling point when the pressure is increased. To the upper side tube attach the bent glass tube so that it points downward. When steam is escaping vigorously, immerse the long glass tube in a jar of water, so that its free end reaches nearly to the bottom of the jar (Fig. 69). Observe the temperature when the mercury becomes steady, so as to determine the effect of increased pressure on the boiling point.

CAUTION. As soon as the reading has been made, withdraw the long tube from the jar so that hot water may not crack the jar. Turn out the flame under the boiler.

Calculation of the True Boiling Point. — The instructor will give you at this point the barometer reading of the day. It has been found that a difference of a millimeter in pressure makes a difference of 0.037° C. in the boiling point. Then for *every* millimeter of the barometer read-

ing in excess of 760 mm., add 0.037° C. to 100° C., or subtract 0.037° C. for every millimeter of barometer pressure less than 760 mm. This gives the *true* boiling point of water under existing barometric conditions.

The difference between this and the observed boiling point will be the *error* of your thermometer at the boiling point. State the *correction* necessary to bring your thermometer to the true boiling point as + or −, according as the boiling point was indicated too low or too high. This correction is added algebraically to indicated temperatures near the boiling point whenever the thermometer is used.

Observations

Number of thermometer	
Reading in melting ice	° *C.*
Reading in free steam	° *C.*
Reading in steam under pressure	° *C.*
Barometer reading	*mm.*

Make sectional drawings of your apparatus, showing how it was used. Write a simple description of how you did each part of the experiment.

Place the table of calculated results at the top of the right-hand page.

Calculated Results

True boiling point for to-day	° *C.*
Boiling point error of the thermometer . . .	° *C.*
Correction for thermometer at boiling point (+ *or* −)	° *C.*
Freezing point error of thermometer . . .	° *C.*
Correction for thermometer at freezing point (+ *or* −)	° *C.*

Discussion:

What is the general effect of pressure on the boiling point? How could you properly graduate a finished blank or ungraduated thermometer?

Conclusion:

The corrections for thermometer No......are ....° C. (+ or −) at the freezing point, and ....° C. at the boiling point. (+ or −)

EXPERIMENT 52

Phenomena of Boiling

OBJECT. To observe what changes occur during boiling and the effect of a dissolved substance on the boiling point.

APPARATUS. Distilling flask, 150 cm.^{3}; ring stand with wire gauze supported on ring; small clamp; perforated flat cork (1″); cork stopper to fit neck of flask and perforated to admit thermometer; beaker; elbow tube and rubber connections; thermometer reading to 100° C.; Bunsen burner; if part (*d*) is to be done, — boiler and hydrometer jar; short pieces of glass tubing or rod.

MATERIAL. Coarse salt.

Introductory:

Our first ideas of boiling were probably obtained from watching the teakettle at home. We knew that the cover should be put on the kettle if the water were to heat quickly. We have seen the lid rise a little and then bump back, until finally steam issued from the spout and a singing noise was heard.

All these familiar sights and sounds are the phenomena of boiling, and boiling means simply the disturbances and changes that occur during the transformation of a liquid into a gas. In a glass flask all these phenomena may be readily observed, and no matter how many times we may see the operations, they lose none of their first fascination.

Experimental:

Arrange the apparatus as in Fig. 70. The position of the cork stopper held in the clamp may have to be adjusted from time to time so that the thermometer scale may be read. The perforated flat cork is slipped over the thermometer and then adjusted in position so that it forms a cap resting on the top of the neck of the flask. The thermometer should slip easily through this cork.

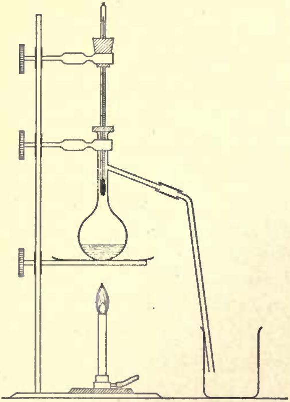

Fig. 70.

Record all observations as soon as made in a tabular form near the top of the left-hand page (see page 188).

(*a*) Have the flask a little less than half full of fresh water. Heat the flask with a small flame, noting where bubbles first form, the size of the bubbles, and what becomes of them (Observation 1). When this *first* bubbling ceases, remove the flame. Slowly lower the thermometer so as to immerse the bulb in the liquid. Note the temperature (Observation 1). Is the water at

its boiling point? *What makes you think that these first bubbles might be air bubbles?*

Raise the thermometer from the water and resume the heating. Note where the bubbles begin to form after a time and what happens to them as they proceed toward the surface (Observations 2 and 3). Take the temperature of the *top* layer of water (Observation 2); also the temperature of the water near the bottom of the flask (Observation 3). *Explain the behavior of the first bubbles in this second heating.*

Raise the thermometer so that its bulb stands just below the opening from the neck to the delivery tube of the flask. Watch the formation and action of the bubbles as the heating continues, increasing the flame if necessary (Observations 4, 5, and 6). When steam is escaping freely from the flask, note the thermometer reading (Observation 4). *Explain.* Then take the temperature of the water near the top (Observation 5) and also at the bottom of the flask (Observation 6). What happens to the steam passing out the delivery tube?

In case your flask *bumps* at any time during the heating, see what happens just before the moment of the bumping.

(*b*) Incline the distilling flask, and let two short pieces of glass tubing or glass rod slide down the inside of the neck. Continue the heating, noting where bubbles form (Observation 7). What is the effect on the rate of boiling? *What is the effect of introducing the glass pieces on the amount of heated surface?*

Glass beads are often used to prevent bumping, as well as to save time in laboratory distillations.

(*c*) Remove the flask from the flame, and after inclining it, slide in about a dozen pieces of coarse salt. Slowly add water until the flask is nearly half full again and, after wiping the outside dry, replace the flask on the gauze. Clamp the thermometer so that its bulb is immersed.

Note the temperature of the liquid when it begins to boil freely[1] (Observation 8). Raise the thermometer so as to take the temperature of the vapor (Observation 9). Taste the condensed liquid coming from the delivery tube. Is it salty?

(*d*) In case Part (*c*) of Experiment 51 (page 183) has not been performed, determine the effect on the boiling point when the pressure is increased. Arrange the apparatus as represented in Fig. 69 on page 183. Then follow the directions given in the first paragraph of (*c*), on that page.

CAUTION. As soon as the reading has been made, withdraw the long tube from the jar, so that the hot water may not crack the jar. Turn out the flame under the boiler.

OBSERVATIONS

NUMBER OF OBSERVATION	POSITION OF THERMOMETER BULB	TEMPERATURE	WHERE BUBBLES FORM AND THEIR BEHAVIOR
(*a*) Water			
1			
2			
3			
4			
5			
6			
(*b*) Pieces of glass			
7			
(*c*) Salt solution			
8			
9			
(*d*) Increased pressure			
10			

[1] *Note to Instructor.* While waiting for the boiling to occur in Part (c), the students should be directed to work on their laboratory notebooks.

Make a drawing of your apparatus. Complete the description of how the experiment was done by statements supplementing the information given in the table of observations.

Discussion:

Answer under this heading the italicized questions occurring in the experimental directions.

What change of state occurs in the vaporization (boiling) of a liquid? in the condensation of a vapor?

Conclusion:

Complete these statements:

A liquid boils best in a flask with a $\left\{\begin{matrix}\text{smooth}\\ \text{rough}\end{matrix}\right\}$ surface. The boiling point of a water solution is ...... than that of pure water. The boiling point is ...... by an increase of pressure.

EXPERIMENT 53

Coefficient of Linear Expansion

OBJECT. **To determine the coefficient of linear expansion of a given material.**

APPARATUS. Any form of linear expansion apparatus, the essentials being: a tube or rod, so mounted that one end is clamped firmly and the other is free to move; if a rod is used, an outer tube to serve as a steam jacket; a steam boiler, with rubber tubing to connect it with the steam jacket or tube; Bunsen burner; thermometer; meter stick; lever and scale, or micrometer screw, for magnifying the elongation.[1]

Introductory:

The fact that bodies expand when they are heated is very familiar. The space left between the ends of the rails on a railroad is designed to allow for the difference in length in winter and summer. Although the proportional expansion is very small, the total change in length of a long structure may be considerable. In order to calculate the total elongation of any body when heated, it is necessary to know the change produced in a unit length by a change in temperature of one degree. This increase in length per unit length per degree Centigrade is called the *coefficient of linear expansion* of the material. As the

[1] As different schools are supplied with different forms of apparatus for this experiment, it was not considered advisable to confine the experimental directions to any one form. The authors would recommend to schools making their own apparatus or purchasing new apparatus, that the expansion of a tube rather than that of a rod be measured, as this greatly simplifies the apparatus. If the tube is just a meter long, and the magnifying ratio of the lever or screw is an even one, as 1 to 20, 1 to 50, or 1 to 100, calculations will be greatly simplified and the pupil will see the result much more clearly.

total increase in length of such a specimen as can be used in the laboratory is very small, a magnifying lever, having a known ratio between the arms, or a micrometer screw, is commonly employed to make possible the accurate calculation of the total elongation.

Experimental:

The length of the specimen furnished is to be directly measured in centimeters and tenths with a meter stick. Care should be taken in this measurement and in the adjustment of the apparatus for the zero reading, to handle the specimen as little as possible, so that its initial temperature may remain that of the room. This temperature is obtained by reading a thermometer which has been in contact with or very close to the specimen for some time.

The specimen is then mounted as directed by the instructor, care being taken that it is free to move only at the end provided with the device for obtaining the amount of elongation. The position of the pointer, or the micrometer head, at the room temperature is then observed to tenths of the smallest division, and recorded. The room temperature is also recorded.

Steam is next passed through the tube, or through the jacket surrounding the rod, for at least ten minutes. If a steam jacketed rod is used, the temperature of the rod may be taken as that of a thermometer whose bulb is inside the jacket in contact with the rod. If a tube is used, through which the steam directly passes, the temperature may be taken as the boiling point of the day, which will be furnished by the instructor.

With the lever form of apparatus, it is only necessary to take the final reading of the pointer and determine the ratio of the lever arms. When a micrometer is used, the screw should be turned back from the end of the rod im-

mediately after taking the reading at room temperature, and, after the tube has reached the temperature of the steam, the screw is again brought in contact with the end of the tube and the reading taken and recorded. Steam should be passing freely when the final readings are taken.

As soon as the readings have been taken, the steam supply should be discontinued, so that the specimen may cool to room temperature as rapidly as possible, and so be ready for a repetition of the experiment if necessary.

All readings taken directly from the apparatus are to be recorded in tabular form near the top of the left-hand page.

Observations

Initial length	*cm.*
Initial scale reading	*cm.*
Final scale reading	*cm.*
Ratio of lever arms	
Room temperature	° *C.*
Steam temperature	° *C.*

Make a simple outline drawing of the apparatus, and write a brief description of the method employed in the experiment.

From the readings obtained, the total elongation, the change in temperature, and the expansion in centimeters per degree Centigrade per centimeter can be obtained by calculation. The results should be entered in tabular form at the top of the right-hand page.

Calculated Results

Difference in scale readings	*cm.*
Total expansion	*cm.*

Difference in temperature . . . . ° *C.*
Expansion per degree C. . . . . *cm.*
Expansion per degree C. per centimeter (linear coefficient) . . . .

Discussion:

Explain the method of calculating the actual expansion from the scale readings, if the lever apparatus was used.

If the micrometer apparatus was used, explain the method of obtaining readings with the micrometer.

Conclusion:

The coefficient of linear expansion of ..... is .....

EXPERIMENT 54

Coefficient of Cubical Expansion

OBJECT. To determine the coefficient of cubical expansion of mercury, relative to glass.

APPARATUS. Specific gravity bottle, 25 cm.^{3}, having a stopper with a capillary hole;[1] ring stand with one ring and wire gauze; thermometer; pipe-stem triangle, with the wire ends doubled under; beaker large enough to permit the bottle, resting on the triangle, to be immersed to a point above the bottom of the stopper; Bunsen burner; balance; weights; one funnel for the class, as described in footnote on page 194.

MATERIAL. Mercury.

Introductory:

The tubes of alcohol thermometers are larger than those of mercury thermometers, because alcohol has a greater

[1] The use of the specific gravity bottle in this experiment was suggested by Mr. Charles H. Slater.

rate of expansion than mercury. Both alcohol and mercury expand more than glass; otherwise the expansion of the glass bulb and stem would cause the liquid column in the stem to fall instead of rise. Since mercury is often contained in glass vessels, as in the thermometer, barometer, and other pieces of apparatus, it is important to know the relative rate of expansion of the two.

A bottle completely filled with a known weight of mercury is heated through a measured change of temperature, and the weight of the mercury which overflows is found. As weights of the same substance are proportional to the corresponding volumes, it is easy to calculate the proportion of the original volume by which the mercury expands for each unit change of temperature. This quantity is the *coefficient of cubical expansion* of mercury. As the glass bottle has been heated to the same temperature as the mercury, the expansion measured is relative to the expansion of the glass, and so the coefficient obtained is relative to glass.

Experimental:

A specific gravity bottle, having a perforated stopper, is filled with mercury under the direction of the instructor.[1] Care must be taken in filling to see that no air is left under the stopper and that the capillary tube in the stopper is completely filled. The bottle should be handled by the neck, to prevent the heat of the hand from forcing

[1] The mercury may well be contained in a funnel, having a jet tube attached by soft rubber tubing, with a screw compressor on the tubing. A porcelain dish is placed beneath it to catch the overflow. At the close of the experiment, the pupils may pour off most of the water from their beakers, and then pour the mercury and remaining water back into the funnel. The separation of water from mercury will then be comparatively easy.

any mercury out. The bottle and its contents are then weighed at room temperature, and both weight and temperature recorded in tabular form near the top of the left-hand page.

The bottle is next placed on a pipe-stem triangle, in a beaker on a ring stand, and water added until it has reached the level of the bottom of the stopper in the bottle (Fig. 71). The water is heated with a Bunsen burner until it boils, and kept at a boiling temperature for 5 minutes. While it is boiling, the temperature of the water is taken with a thermometer and recorded. Observe what happens to the mercury in the bottle.

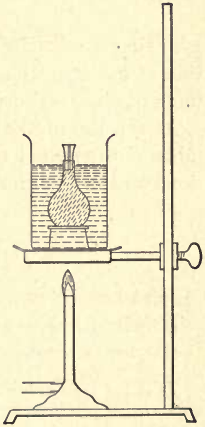

Fig. 71.

The beaker is now removed from the ring stand. By dipping out hot water and adding cold water, the temperature of the water is brought approximately to that of the room. Care must be taken during this operation to avoid getting any water into the specific gravity bottle. The bottle is now removed from the water, carefully dried, and again weighed.

After being weighed, the bottle is returned to the instructor, still containing the mercury. The greater part of the water in the beaker is to be poured off, without losing any mercury. The remaining water and mercury is to be disposed of as the instructor may direct.

The readings taken should be entered in a tabular form near the top of the left-hand page.

Observations

Weight of empty bottle	*g.*
Weight of bottle filled with mercury, initial . .	*g.*
Weight of bottle with mercury, final	*g.*
Initial (room) temperature	°*C.*
Final (boiling) temperature	°*C.*

A simple drawing of the apparatus and a brief description of the operations in the experiment should follow the table of observations on the left-hand page.

At the top of the right-hand page, place the following table of calculated results, making the required computations on the page immediately beneath the table.

Calculated Results

Initial weight of mercury (a)	*g.*
Weight of mercury lost by expansion (b) . .	*g.*
Change in temperature (c)	°*C.*
Loss by expansion per degree $\left(d = \frac{b}{c}\right)$ . . .	*g.*
Coefficient of cubical expansion $\left(\frac{d}{a}\right)$	

Discussion:

Explain clearly how the loss in weight per degree, divided by the original weight, gives the coefficient of cubical expansion.

Conclusion:

The coefficient of cubical expansion of mercury relative to glass is _____.

EXPERIMENT 55

Increase in Volume at Constant Pressure

OBJECT. To find the relation between the increase in the volume of a gas and the increase in temperature causing the change, when the pressure remains constant.

APPARATUS. Steam boiler with chimney, having the lower side outlet closed with a rubber tube and a screw compressor; Charles' law tube, Waterman form; thick cardboard square, 3″ × 3″, perforated to admit Charles' law tube; narrow jar or cylinder about 8″ high; thermometer; ring stand and clamp; Bunsen burner.

MATERIAL. Finely cracked ice, or snow.

Introductory:

The expansion of solids by heat is a familiar fact. The rate at which metals expand for each degree of temperature has been carefully studied. It has been found that each metal has its characteristic rate (coefficient of expansion). With gases, however, the rate is the same for them all, but its determination is made more difficult by the fact that the volume of a gas is also affected by atmospheric pressure. The effect of this pressure in the expansion of solids is so slight that it is disregarded in the determination of their coefficient of expansion.

As the atmospheric pressure seldom varies much in a short time, the effect of an increase of temperature on the volume of a gas is found by measuring the volume at two different temperatures and under atmospheric pressure. The two most convenient temperatures for the determination are 0° C. and 100° C., respectively, as these temperatures are easy to obtain with ice and steam. The gas is confined in a Charles' law tube by means of a mercury

plug, which is free to move as the volume of the gas changes.

The relation between volume and temperature under constant pressure is most conveniently expressed with reference to the absolute scale of temperature. On this scale the zero corresponds to – 273° C. The Centigrade zero is equivalent to 273° A. To change Centigrade temperatures to absolute temperatures, add 273° algebraically.

Experimental:

With the steam boiler half full of water, light the burner underneath, and screw on the chimney. The lower outlet for the escape of steam should be closed by a screw compressor on a rubber tube. While waiting for the water to boil, determine the volume of inclosed air at 0° C. as directed in (*a*).

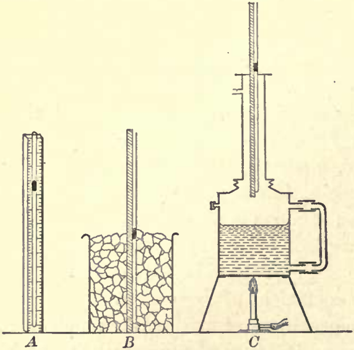

Fig. 72.

(*a*) The mercury index in the Charles' law tube should stand at about the center of the graduated scale. Insert the tube, with its scale, in a jar containing finely cracked ice, or snow, so that the mercury index is a short distance above the surface of the ice. Note the descent of the index as the inclosed air contracts. When no further contraction occurs and the inclosed air is all surrounded

by melting ice (Fig. 72, B), take the reading of the index on the graduated scale. Since the tube is of uniform diameter, the length of the inclosed column of air may be taken as the measure of its volume. Record the reading in a tabular form near the top of the left-hand page.

(*b*) Remove the air tube from the ice, and allow it to stand five minutes or so in the air to regain the room temperature. Then slowly slip the tube with its scale through the cardboard cover on top of the chimney of the boiler. The mercury index should be just visible above the cardboard (Fig. 72, *C*). When the column of inclosed air has been brought to the temperature of the steam, the index will become stationary. Clamp the tube in this position, with the index just above the cardboard, then read and record the position of the index on the scale. Remove the tube from the boiler.

Insert the bulb of a thermometer in the steam within the chimney. When the mercury becomes stationary, read and record the temperature.

OBSERVATIONS

Length (volume) of inclosed air at 0° *C.* . .	*cm.*
Length (volume) of inclosed air at steam temperature	*cm.*
Temperature of the steam	°*C.*

Make simple drawings, showing the Charles' law tube in position at each of the two temperatures. Briefly describe the experimental method.

Change the Centigrade temperatures to absolute temperatures, and record in a table of calculated results placed at the top of the right-hand page.

Find (*a*) the increase in volume of the air; (*b*) the fraction of the original volume which this increase is,

expressing the result to three decimal places; (*c*) the fractional (decimal) increase in temperature over the initial absolute temperature. Record these in the table.

Calculated Results

0° Centigrade	*° absolute*
____*° Centigrade*	*° absolute*
Increase in length (volume) of inclosed air	*cm.*
Fractional increase in volume . —— =	
Fractional increase in temperature —— =	

Discussion:

Why was the inclosed gas regarded as being under constant pressure? Compare the two decimals representing the fractional increases in volume and in temperature (absolute scale). What would be the fractional increase in volume for one degree? for twenty degrees? What would be the fractional decrease in volume when the gas was cooled ten degrees? In each case assume the original temperature to be 0° C.

Conclusion:

Complete this statement:

Under constant pressure, the volume of a gas is____ to its temperature on the ____ scale.

EXPERIMENT 56

Increase in Pressure at Constant Volume

OBJECT. To find the relation between the increase in pressure of a gas and the increase in temperature causing this change, when the volume of the gas remains constant.

APPARATUS. Charles' law tube (Hall and Bergen form); glass condenser with inner tube removed; 1-hole cork stopper to fit opening at one end of condenser tube and solid cork for other end; ring stand with condenser clamp; ring stand with small clamp for raising free end of Charles' law tube; steam boiler with cap; rubber tubing to connect steam boiler with condenser tube; tubulated ice tray with 1-hole cork to fit; burner; meter stick; beaker.

MATERIAL. Cracked ice, or snow.

Introductory:

If a hot fire is maintained under a steam boiler when the engine is not running, the steam pressure increases and, if it were not for the safety valve, the boiler would burst. When a tea kettle begins to boil, the pressure of the steam lifts the lid. In both of these cases a gas, steam, is heated in such a way as to prevent it from expanding. In our experiment, a certain amount of air will be confined in a tube at the temperature of melting ice; it will then be heated to the temperature of steam, but its volume will be kept the same by increasing the pressure upon it. From our results we may reach a conclusion regarding the relation between the temperature of a gas and its pressure, when the volume is kept constant. The Centigrade temperatures given by our thermometer will be changed to *absolute* temperatures by adding 273° algebraically to the Centigrade reading.

Experimental:

CAUTION. Do not allow the open end of the Charles' law tube to get below the horizontal position, or the mercury may run out.

See that the steam boiler is half full of water, the cap in place, and the steam outlet at the side open. Connect with rubber tubing the steam outlet of the boiler with the steam inlet of the steam jacket (condenser tube). Place a beaker beneath the outlet tube of the condenser, Fig. 74, to catch any condensed steam. Light the burner under

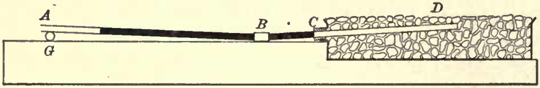

Fig. 73.

the boiler, so that there will be a supply of steam ready for the steam jacket.

(*a*) Pass the closed end of the air tube through the cork of the ice tray and cover this portion of the tube with finely cracked ice. When the inclosed air column no longer contracts, adjust the position of the tube in the stopper, so that the mercury in the tube extends just to the outer end of the stopper (*C*, Fig. 73). The other end of the mercury column should be at the same height above the table top as the mercury at *C*, so that the volume, *CD*, of inclosed air will be at atmospheric pressure. The necessary elevation may be obtained by the use of a small piece of glass tubing (*G*, Fig. 73).

Measure the distance from *C* to *B*, the nearer end of the rubber connection, and record in the table of observations near the top of the left-hand page.

(*b*) Remove the air tube with its stopper from the ice tray, and fit it into the steam jacket (Fig. 74) so that the distance *BC* is just the same as with the ice tray.

Support the outer end of the air tube in a movable clamp on a vertical support. As the air in the tube expands, keep raising the level of the outer tube (*AB*, Fig. 74), so that the inner end of the mercury column extends just to *C*. By this means the volume of the inclosed air is kept the same as the volume of the air which was measured at 0° C.

In order to keep this volume of air constant, it has been necessary to increase the pressure upon it by raising a

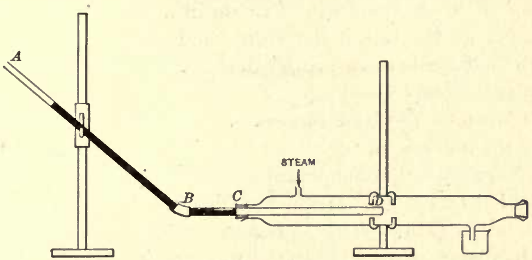

Fig. 74.

portion of the mercury column. The increase in pressure, in millimeters of mercury, is the difference between the height of the outer and the inner ends of the mercury column. Determine these vertical distances above the table top and record them in the table. Also read the barometer and record the reading.

Observations

Part (a) Temperature 0° C. (melting ice)

Length BC	*mm.*
Pressure of inclosed air (Barometer reading)	*mm.*

Part (b) Barometer reading . . . . *mm.*

Height of outer end of mercury above table top	*mm.*
Height of inner end of mercury above table top	*mm.*

Make simple drawings, showing the arrangement of the air tube at each of the two temperatures. Briefly describe the experimental method, with particular reference to the means of keeping the volume constant.

Calculate the boiling point of water (temperature of steam) at the observed barometric pressure. This is done by adding to 100° C., 0.037° for each millimeter of barometric pressure above 760 mm., or subtracting the same amount from 100° C. for each millimeter below 760 mm. Record this temperature of steam in a table of calculated results at the top of the right-hand page. Change the two Centigrade temperatures to the corresponding absolute temperatures, by adding 273°, and record.

Calculate (*a*) the increase in absolute temperature; (*b*) the increase in pressure; (*c*) the total pressure of the inclosed air at the temperature of steam; (*d*) the decimal fraction (three places) which the increase in pressure is of the initial (atmospheric) pressure; the fractional increase in temperature over the initial temperature, using absolute degrees, expressed as a decimal (three places).

Calculated Results

0° *Centigrade*	=	° *absolute*
-----° *Centigrade (temperature of steam)*	=	° *absolute*
Increase in absolute temperature of inclosed air		° *absolute*
Increase in pressure of inclosed air		*mm.*
Total pressure of inclosed air at steam temperature		*mm.*
Fractional increase in pressure of air		
Fractional increase in absolute temperature of air		

Discussion:

Compare the fractional increase in pressure with the fractional increase in absolute temperature. How much was the increase in pressure for each degree absolute?

Conclusion:

Complete this statement:

When the volume of a gas is kept constant, the pressure of the gas is ----- to its temperature on the _____ scale.

EXPERIMENT 57

Law of Heat Exchange

OBJECT. To find the relation between the heat lost by a hot body and the heat gained by a cold body, when the two are brought in contact.

APPARATUS. Boiler, with dipper to fit; calorimeter; small battery jar; perforated cardboard square; graduate (100 $cm.^3$); flask (250 $cm.^3$), with 1-hole rubber stopper to fit; 2 thermometers; Bunsen burner; balance; metric weights; an ice shaver (Fig. 75) is convenient.

MATERIAL. Shaved ice or snow in covered crock; several pailfuls of hot water; cotton batting.

Introductory:

When cream is poured into hot coffee, the mixture becomes cooler than the coffee and warmer than the cream. A tub of hot water apparently loses heat when cold water is run into it. What really happens is the gaining of heat by the cold water at the expense of the hot water. Does such a transfer of heat take place according to any fixed principle? This question may be answered by mixing

weighed amounts of hot and cold water, each of known temperature, and taking the temperature of the mixture.

In order to make the calculations required to establish the law of heat exchange, it is necessary to define a unit of heat measurement, called the *calorie.* This is the amount of heat which will raise the temperature of one gram of water one degree Centigrade.

Experimental:

Handle the thermometers carefully, as the glass forming the bulb is very thin. Do not pour hot water on a cold thermometer, nor cold water on a hot thermometer. Keep your note-book close at hand, so as to record the temperatures as soon as read. Read all temperatures to tenths of a degree.

Measure with a graduate 200 cm.^{3} of water into the dipper of the steam boiler. See that the boiler is about half full of water and then light the burner beneath it. While waiting for the water to heat, do Part (*a*).

(*a*) Weigh the calorimeter empty and dry. Put shaved ice, or snow, into a graduate up to the 15 cm.^{3} mark and then add water to the 100 cm.^{3} mark. Pour the mixture into the calorimeter and weigh again. Keep the outside of the calorimeter wiped dry during the weighing. Place the calorimeter in a battery jar, filling the space between the two with cotton wool or other non-conducting packing. Cover the top of the calorimeter with a cardboard square, having a hole in the center, through which a thermometer is inserted.

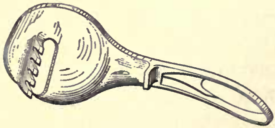

Fig. 75. Ice Shaver.

Measure 100 cm.^{3} of water into an Erlenmeyer flask fitted with a 1-hole rubber stopper, carrying a ther-

mometer adjusted so that the bulb is near the bottom of the flask when the stopper is in place.

Warm the water in the flask by dipping the flask into a pail of hot water. A slight rotary motion given to the flask will insure uniform heating. The water is to be heated to as many degrees above the room temperature (which will be placed on the blackboard) as the temperature of the water in the calorimeter is below the room temperature. Read and record promptly the temperatures of the two masses of water.

Then lift off the cardboard cover from the thermometer in the calorimeter. Pour the warm water from the flask into the calorimeter, letting it run down the thermometer which was used in the flask. For about half a minute stir the mixture of warm and cold water, using both thermometers with the bulbs held together. Read and record the average reading of the two thermometers.

Touch the bulbs of the thermometers to the side of the calorimeter to remove any adhering water, and take them out of the vessel. Weigh the calorimeter and its contents, and record.

Place one of the thermometers in the water in the calorimeter and keep it for Part (*b*), as this is the mass of cold water to be used in that part of the experiment.

(*b*) By this time the water in the dipper will probably be hot. Carefully introduce a thermometer and stir until the temperature of the water is ascertained. Record this at once. Then quickly read and record the temperature of the water in the calorimeter.

Pour the water from the dipper into the calorimeter, and stir with the two thermometers for about half a minute. Read and record the average reading of the two thermometers. Weigh the calorimeter and the mixture. Record.

Observations

	Part (a)	Part (b)
Weight of calorimeter empty . .	...... g.	...... g.
Weight of calorimeter and cold water	...... g.	...... g.
Weight of calorimeter and mixture	...... g.	...... g.
Temperature of cold water . .	......° C.	......° C.
Temperature of warm (or hot) water	......° C.	......° C.
Temperature of mixture . . .	......° C.	......° C.
Temperature of room	......° C.	......° C.

Describe briefly the essential operations in each part of the experiment. Make a sectional drawing of the calorimeter and battery jar, showing how the calorimeter was protected from loss or gain of heat from without.

Calculate in both parts of the experiment the calories (1) lost by the warm (or hot) water, (2) gained by the cold water. The weights of water mixed can be found from the weights recorded. The temperature of the room is not to be considered in the calculations. Record the results in tabular form at the top of the right-hand page.

Calculated Results

	Part (a)	Part (b)
Weight of cold water . . .	...... g.	...... g.
Weight of warm (or hot) water	...... g.	...... g.
Fall in temperature of warm water	......° C.	......° C.
Rise in temperature of cold water	......° C.	......° C.
Calories of heat lost by hot water	...... cal.	...... cal.
Calories of heat gained by cold water	...... cal.	...... cal.

Discussion:

Define a calorie. If there was an inequality in the calories of heat lost and gained, some heat must have been wasted. Could the calorimeter, the thermometers, or the air account for heat wasted? Explain. Why is it desirable to have the temperature of the mixture the same as the room temperature? Which part of the experiment should give you the closer agreement in its results? Why?

Conclusion:

Complete the following statement:

The number of calories of heat lost by a hot body equals

EXPERIMENT 58

Specific Heat of a Metal

OBJECT. To find the specific heat of lead by the method of mixtures.[1]

APPARATUS. Lead cylinder with conical top, weighing about 600 g. to 700 g., having a stout linen thread for suspension; spring balance (2000 g.); boiler; Bunsen burner; thermometer; graduate; calorimeter.

Introductory:

An empty tea kettle, placed on the stove, soon reaches a temperature equal to that of boiling water. If, however, a weight of water be poured into the kettle equal to its own weight, it will take several times as long to bring the water to the boiling temperature. That is, more heat is

[1] Iron or aluminum may be used in place of lead, if the instructor prefers; the lead cylinders, however, can be easily cast, and the use of a single solid piece of metal is decidedly preferable to shot.

required to heat one pound or one gram of water one degree than is required to heat one pound or one gram of iron one degree. No other solid or liquid requires as much heat to raise one gram of it one degree as water requires for the same change; the other substances absorb or give out less than one calorie per gram per degree. The fraction of a calorie absorbed or given out when one gram of a substance changes temperature through one degree, is called the *specific heat* of the substance.

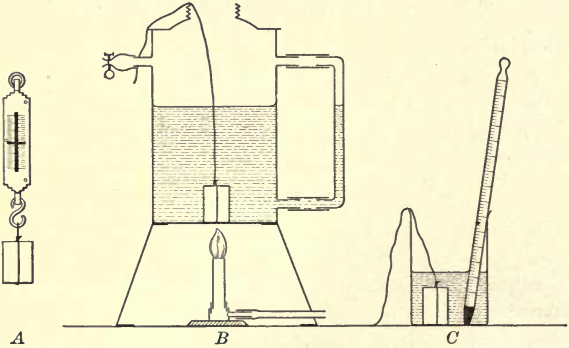

Fig. 76.

By heating a weighed piece of lead to the temperature of boiling water and then cooling it in a known weight of water at a certain temperature, the calories given to the cold water by the hot lead can be calculated, and also the calories yielded by each gram of lead for each degree change in its temperature.

Experimental:

Fill the boiler half full of cold water and light the burner underneath it. Weigh the lead cylinder (Fig. 76,

A) and record its weight in a table of observations placed near the top of the left-hand page. Place the cylinder in the boiler, and allow it to remain there for five minutes after the water begins to boil freely.

While the lead is being heated, measure out into the calorimeter 300 cm.^{3} of *cold* water from the tap. Record the weight of water taken, considering 1 cm.^{3} equivalent to a gram.

When the lead has reached the temperature of the boiling water, read and record the temperature of the *cold* water. Quickly raise the lead with the thread, touching it to the edge of the boiler as it is taken out so as to dislodge any drops of water, and place the lead in the cold water. Stir the water with the thermometer immediately after adding the lead, and take the temperature. Record this in the table.

In case you have not determined in a previous experiment the water equivalent of your calorimeter, obtain its value from the instructor.

Observations

Weight of lead cylinder	*g.*
Weight of cold water	*g.*
Water equivalent of calorimeter	*g.*
Temperature of the lead	° *C.*
Temperature of cold water	° *C.*
Temperature of lead and water in calorimeter	° *C.*

Make simple outline drawings, showing the three steps in the experiment, and describe the method with reference to these drawings.

The weight of the cold water plus the water equivalent of the calorimeter, multiplied by their rise in temperature, gives the number of calories gained by the cold water and

the calorimeter. Record this value in a tabular form near the top of the right-hand page.

This heat gained by the water and the calorimeter was given out by the lead in cooling. Assuming the lead to be at the temperature of boiling water, compute the decimal part of a calorie given out when one gram of lead cools one degree Centigrade.

Calculated Results

Weight of water + water equivalent of calorimeter	*g.*
Temperature change of water and calorimeter	*° C.*
Total calories gained by water and calorimeter	*cal.*
Total calories given out by lead in cooling......*° C.*	*cal.*
Total calories given out by lead in cooling 1° *C.*	*cal.*
Calories given out by 1 *gram of lead in cooling* 1° *C.*	*cal.*

Discussion:

Why is it desirable to have the temperature to which the water is raised by the lead, the same as the temperature of the room?

Conclusion:

Define specific heat. What do you find the specific heat of lead to be?

EXPERIMENT 59

Cooling through Change of State

OBJECT. To observe the heat changes taking place during the solidification of acetamid.[1]

APPARATUS. Four-inch test tube, three fourths full of acetamid crystals, and provided with a one-hole stopper, through which passes a thermometer (0° C. to 100° C.) ; ring stand with one ring, wire gauze, and clamp for test tube; Bunsen burner; beaker of water.

Introductory:

When we melt ice by the use of heat, we notice that it takes considerable time. Heat energy must be entering the ice, and yet does not warm it. This heat energy is used up in melting the ice. In order to freeze water back into ice, this heat energy must come out of the water. Tubs of water are sometimes placed in cellars to prevent vegetables from freezing. As the temperature of the cellar falls, the water begins to freeze first. In so doing, it gives out heat enough to prevent the air from falling as far below the freezing point as it otherwise would do. Heat continues to be given out by the water as long as it is freezing.

It is possible to observe these changes more easily in some other substances than it is in ice. When we melt substances and then allow them to crystallize, they give out the same amount of heat which is needed to melt the crystals. This heat, which becomes apparent on solidification, makes the substance warm the containing vessel

[1] "Hypo" (sodium thiosulphate) may be substituted for acetamid, but the results are not as satisfactory. If hypo is used, the tube, after the hypo has been melted, will need to be cooled in a beaker of cold water.

and surrounding objects. We wish to observe the changes in temperature before, during, and after the crystallization process in some melted acetamid.

Experimental:

Support a test tube containing crystals of acetamid in a beaker of water on a ring stand (Fig. 77). Melt the acetamid by heating the water. As soon as it is completely liquefied the thermometer should be inserted in the acetamid, so that the bulb shall be entirely covered. If necessary, continue to apply heat until the temperature is above 90° C., but not over 95° C. In all readings, tenths of a degree should be estimated.

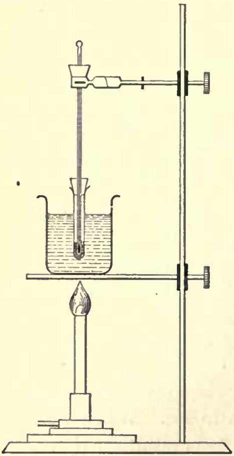

Fig. 77.

Remove the burner and the beaker of water, and allow the tube to cool in air, without being disturbed in any way. Every half minute take a reading of the temperature. The tube should be closely watched at all times, and at the instant solidification begins, a reading should be taken and marked *S* in the table, to distinguish this point. Continue the readings at half-minute intervals, until solidification is complete, and then at one-minute intervals until a temperature of about 55° C. is reached. At the close of the experiment the tube and thermometer should be returned to the instructor, without any attempt to remove the thermometer from the acetamid.

Record the observations in tabular form near the top of the left-hand page.

OBSERVATIONS

Time in minutes .	0	$\frac{1}{2}$	1	$1\frac{1}{2}$	2	$2\frac{1}{2}$, *etc.*
Temperature in ° C.	—	—	—	—	—	—, *etc.*

An outline drawing of the apparatus and a brief description of the operations should be placed immediately below the table of readings.

Curve. — On a sheet of cross-section paper, plot a curve from your readings. Allow two horizontal spaces (2 mm.) for a half minute, and one vertical space (1 mm.) for one degree. This curve is to be pasted by its edge to the top edge of the right-hand page.

Discussion:

Answer each question with a complete sentence.

Is there any point where the temperature curve takes a sudden change? Does this correspond to any change in the condition of the acetamid? Does your curve indicate that acetamid has a definite melting (or freezing) point? If so, at what temperature? Is this temperature maintained while solidification is taking place? Is heat required to keep a body at a temperature above that of the room? As no heat is being applied externally, from what change in the acetamid must this heat come?

Conclusion:

Does a substance give out heat or absorb heat during solidification?

EXPERIMENT 60

Melting Points and Boiling Points

OBJECT. To learn the method of determining the melting points and boiling points of substances; and to study the boiling points of a mixture of alcohol and water.

APPARATUS. Ring stand; ring; two burette clamps; asbestos square, or iron gauze with asbestos center; beaker (100 cm.^{3}); glass stirrer; thermometer; rubber band (section of rubber tubing; capillary tubes;[1] distilling flask (60 cm.^{3}); cork to fit flask and perforated to admit thermometer; small Liebig condenser, or 2 ft. length of $\frac{1}{2}''$ tubing, with cork stopper perforated to admit delivery tube of distilling flask; glass beads or a few short pieces of glass tubing; small graduate (preferably 25 cm.^{3}); Bunsen burner.

MATERIAL. Stearic acid; naphthalene or moth-balls; carbon tetrachloride; grain alcohol.

Introductory:

The melting point of a substance is the transition temperature between its solid and liquid state. The boiling point marks the boundary between the liquid and the gaseous states. A considerable change in pressure is necessary to affect the melting point of a solid; the temperature at which a liquid boils changes with even the ordinary variations of atmospheric pressure.

Determinations of the melting point are valuable in that they indicate the purity of a substance. A pure sub-

[1] The capillary tubes are made by heating the middle of a short piece of glass tubing. When the tubing is soft in the heated portion, draw it out into a thin-walled tube about 1 mm. in diameter. With a file cut off lengths of $2''$ to $3''$ and seal the narrower end of each in the Bunsen flame.

stance, melting at a certain definite temperature, melts below that temperature when it contains even a very small amount of another substance. Crystalline solids are characterized by very definite melting points.

Boiling points are very useful in the identification of liquids and as an indication of their purity. In the purification or separation of liquids by distillation, the observed boiling points are the guides to the steps in the process.

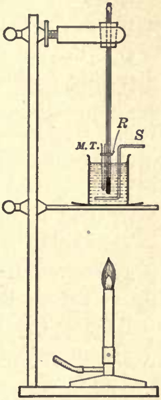

Fig. 78.

Experimental:

Melting Points. — (*a*) Light the burner underneath the beaker of water (Fig. 78). Have a very small flame, so that the water will heat very slowly.

Put the open end of a capillary tube into some stearic acid, so as to get a column of the solid several millimeters in length. Turn the tube upright and tap the closed end gently on the table, so that most of the solid falls to the bottom of the tube. Slip the tube through the rubber band (Fig. 78, *R*) on the thermometer so that the solid is in the position indicated in Fig. 78.

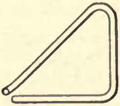

Fig. 79.

Move the glass stirrer[1] up and down in the beaker until you see some of the small particles sticking to the capillary walls melt. Read the temperature and record it as the melting point of the stearic acid in a tabular form on the left-hand page. In case you heated the water too

[1] The bottom of the glass stirrer is most conveniently made by bending the glass into a triangular form as shown in Fig. 79.

rapidly, let it cool a little and approach the melting point more cautiously, using a fresh tube of the stearic acid.

(*b*) Determine in a similar manner the melting point of naphthalene (the principal constituent of moth balls).

(*c*) Put 15 cm.^{3} of carbon tetrachloride into a small distilling flask having the delivery tube pointing upward as you pour the liquid in. Then arrange the flask as in Fig. 70, and pass the delivery tube of flask through a cork fitting into a condenser, with a beaker to receive the distillate. A few short pieces of glass tube in the flask will save time in bringing the liquid to a boil. Take as the boiling point of the carbon tetrachloride, the steady temperature obtained as the liquid distills off through the delivery tube. Record.

Remove the burner and empty the distilled and the undistilled tetrachloride into the bottle indicated by the instructor.

(*d*) After rinsing out the distilling flask and the beaker with a very little grain alcohol, pour into the flask 15 cm.^{3} of alcohol and 14 cm.^{3} of water. This gives a mixture which is very nearly 50 per cent alcohol.

Have at hand a sheet of cross-section paper. According to a scale given by the instructor, temperatures are to be plotted on the vertical axis and the volumes (cm.^{3}) of the distillate on the horizontal axis.

Heat the diluted alcohol to boiling, and plot as the first temperature that obtained when the liquid begins to condense in the delivery tube of the flask. Read the temperature from this point on as soon as each successive 3 cm.^{3} of the distillate is collected. Plot the readings as soon as made. Paste the cross-section paper by an edge in the note-book.

OBSERVATIONS

Melting points, Stearic acid		°*C.*
Naphthalene		°*C.*
Boiling point, Carbon tetrachloride		°*C.*

Make drawings showing both the melting-point and the boiling-point apparatus. Describe the experimental methods with reference to these drawings.

Discussion:

The boiling point of ordinary alcohol is 78.4° C. What effect does the water in the 50 per cent alcohol have on the boiling point of the alcohol? Between what temperatures does most of the alcohol distill? (Examine the curve.) How many cubic centimeters of distillate were collected between these two temperatures? What liquid is present in the larger amount during the latter part of the distillation? What makes you think so? Is the boiling point of water raised when it contains a little alcohol?

Conclusion:

What difference do you notice between the boiling point of a pure substance and the boiling point of a solution? How does a liquid dissolved in a second liquid affect the boiling point of the second liquid?

EXPERIMENT 61

Heat Changes during Solution and Evaporation

OBJECT. To observe the heat changes which accompany solution and evaporation.

APPARATUS. Centigrade thermometer; 50 $cm.^3$ beaker; wooden block; bicycle pump or foot bellows; two 100 $cm.^3$ Erlenmeyer flasks; battery jar or other receptacle for hypo solution; test tube.

MATERIAL. Strips of cheesecloth one inch wide; alcohol; ether; "hypo" crystals; supersaturated solution of hypo, made by dissolving 100 g. of hypo in 20 $cm.^3$ of water for each 100 $cm.^3$ flask.

Introductory:

Photographers notice that a freshly made "hypo" solution feels much colder than the water used in making it. Is there an actual fall of temperature during solution?

Camphor is rubbed on the head for headache; alcohol baths are given to fever patients. On a hot day we feel cooler in a breeze. In each of these cases rapid evaporation takes place on the skin. Is or is not the body actually cooled by this evaporation?

CAUTION. No flame is to be allowed in the laboratory during this experiment, and at the close the windows should be opened wide.

Experimental:

(*a*) A thermometer bulb is wrapped with a strip of cheesecloth, which is then tied with a raveling from the cloth. The thermometer is held by the upper part of the stem and a reading taken. Continue to hold the thermometer by the stem; then dip the bulb into a test tube

of alcohol and remove it when the cloth is thoroughly wet. The cloth is allowed to dry, in a draft if possible, the temperature being constantly watched. Record the temperature (1) immediately before dipping into the alcohol, (2) immediately after withdrawing the bulb from the alcohol, (3) at the reading showing the greatest change from the temperature taken in (2). *Is the change in temperature that you noticed due to the temperature of the alcohol, or is it the result of the evaporation of the alcohol?*

(*b*) A few drops of water are placed on a wooden block and a beaker is set down in the water, so that there will be a film of water between the beaker and the block. Enough ether is poured in the beaker to cover the bottom.

Cork the ether bottle tightly and do not inhale the fumes during the experiment.[1]

With a bicycle pump or a foot bellows having a piece of rubber tubing connected to it, blow *gently* on the surface of the ether until it is evaporated. What has happened to the water? If there is no marked change of state in the water, repeat, using a little larger amount of ether. *Has the ether, while evaporating, absorbed heat from the water or lost heat to it? Explain.*

(*c*) Into a small, clean flask are placed enough crystals of hypo to fill the flask a third full. Water, whose temperature has been observed and recorded, is added till the crystals are just covered. The flask is then shaken vigorously with a rotary motion until as much as possible of the hypo has dissolved. The bottom of the flask is then felt with the hand. Result? The thermometer is in-

[1] This part of the experiment must be carried on where there is a good draft to remove the ether vapor. If this condition cannot be met, or if the class is large, it is advisable to call the class together and perform this test as a demonstration.

serted in the solution and the temperature taken and recorded. *Has the water taken heat from the hypo or given heat to it during the process of solution?* The result obtained with hypo is typical of the heat change in solution, when no chemical action takes place between the dissolved substance and the solvent.

After the temperature of the solution has been observed, it should be placed in a receptacle indicated by the instructor, so that the hypo may be recovered by the evaporation of the water.

(*d*) At each laboratory table is placed one or more flasks with the necks plugged with cotton, each containing a supersaturated solution of hypo, which has stood in the room long enough to reach room temperature. When the students at a table have completed and recorded the results of the preceding parts of the experiment, they should make this final test together. Each student should touch the flask with his finger, without moving the flask or disturbing the liquid. The cotton should then be removed and a crystal of hypo dropped in. Result? When the change is complete, each student should feel of the flask and record his observation. *What heat change takes place when the hypo is dissolved? When the hypo comes out of solution, what heat change occurs?*

The results of Parts (*a*) and (*c*) should be recorded in tabular form near the top of the left-hand page. Other observed results should be recorded in the description of the part of the experiment to which they belong.

Observations

Part (*a*):

Temperature of room (1) . . . . ° *C.*
Temperature of alcohol (2) . . . . ° *C.*
Extreme temperature noticed (3) . . . . ° *C.*

Part (c):

Temperature of water before dissolving hypo . ° *C.*
Temperature of hypo solution . . . . . ° *C.*

Drawings should be made of the apparatus used in parts (*a*) and (*b*). A brief description of the tests and of all results not noted in the table should follow the table.

Discussion:

Answer, under this heading, the italicized questions occurring in the experimental directions.

Conclusion:

Is sensible heat absorbed or given out when a liquid changes to a gas? When a solid dissolves?

EXPERIMENT 62

Heat of Fusion of Ice

OBJECT. **To find the number of calories of heat required to change one gram of ice to water without warming the ice water above the melting point of the ice.**

APPARATUS. Calorimeter; thermometer; graduate, or balance and weights; 150 $cm.^3$ beaker.

MATERIAL. Supply of ice cracked into pieces about the size of a hickory nut; supply of hot water at about 50° C.

Introductory:

When water at boiling temperature is thrown upon ice that is just ready to melt, some ice will melt and the boiling water will be cooled down to the freezing point. If just enough boiling water to melt the ice is used, it will

be found that there will be one and a quarter times as much ice melted as there was boiling water, and the whole mass will be ice cold.

What becomes of the heat that was in the boiling water? When heat is continuously applied to a solid body, as when pieces of ice are stirred about quickly in a pan on a hot stove, the solid is heated only up to the melting temperature. If stirred vigorously, the melted part and the part not yet melted do not get warmer than the melting temperature until the last bit is melted. After this the liquid will get warmer.

We wish to find how much heat must be applied and must disappear as heat energy, when we change a definite amount of a solid to its liquid state. This number of calories is called the *heat of fusion* of the substance.

Experimental:

(*a*) In the calorimeter are to be placed 300 $cm.^3$ of hot water.[1] Since the calorimeter is being heated or cooled at the same time as the water in it, this fact must be taken into account in the calculations. The number of grams of water which require the same amount of heat to raise them one degree as is required to raise the temperature of the calorimeter one degree, will be furnished by the instructor. This number of grams, called the water equivalent of the calorimeter, is always to be added to the number of grams of water actually placed in the calorimeter.

(*b*) Insert the thermometer into the water, and when the temperature becomes about 50° C., begin to add *dry*

[1] If the instructor prefers, the masses of water and ice may be found by direct weighing. The method of measurement used here is much simpler, and the results are accurate within the limits of error which may be expected in the experiment.

ice, and continue until enough dry ice to fill a 150 $cm.^3$ beaker has been added. Stir constantly. As soon as the last particle of ice has been melted, give one final stir and take the temperature at once. Record this temperature as well as the first temperature, in a table near the top of the left-hand page.

(*c*) Measure the contents of the calorimeter and record the volume obtained.

Observations

Volume of hot water	*cm.*^{3}
Final volume of water and melted ice . . .	*cm.*^{3}
Initial temperature (at instant of beginning to add ice)	*°C.*
Final temperature (at melting of last piece of ice)	*°C.*
Water equivalent of the calorimeter . . .	*g.*

Calculation of Results. — (1) Calculate, from the final volume of liquid in the calorimeter, the mass of ice used.

(2) Calculate the number of calories of heat given up by the original hot water and the calorimeter, in cooling from the initial to the final temperature. This is the total number of calories available to melt the ice and warm the ice water. Calculate the number of calories used in raising the temperature of the melted ice from 0° C. up to the final temperature.

(3) From these two results calculate:

(*a*) The total number of calories that were used in melting all the ice.

(*b*) The number of calories needed to melt one gram of ice.

These calculated results should be entered in a table at the top of the right-hand page.

Calculated Results

Total hot mass (mass of water + water equivalent of calorimeter)	*g.*
Cold mass (ice)	*g.*
Change of temperature	*° C.*
Calories given up by hot water	*cal.*
Calories absorbed in warming melted ice to final temperature	*cal.*
Calories absorbed in melting all the ice . .	*cal.*
Calories absorbed in melting one gram of ice	*cal.*

Discussion:

Explain why it is important to use *dry* ice.

Explain how the last three numbers in the table of calculated results are obtained.

Conclusion:

The heat of fusion of ice is ----- calories.

EXPERIMENT 63

Heat of Vaporization

OBJECT. To determine the number of calories of heat that are liberated when one gram of steam at 100° C. is converted into water at 100° C.

APPARATUS. Boiler; steam trap; glass and rubber tubing as shown in Fig. 80; Bunsen burner; calorimeter; thermometer; graduate, 100 cm.³

Introductory:

Farmers often cook a large quantity of feed for their stock in the following manner: They take steam from

a boiler through a pipe or hose. The end of this pipe is pushed down under cold water in a barrel. The cold water condenses the steam and is heated very quickly by the heat which the steam gives up. The steam first gives up heat in condensing to drops of boiling water, and these drops of boiling water give up heat while they cool down to the final temperature of the water in the barrel. A surprisingly large number of calories of heat is thus given to the barrel of water, by a comparatively small weight of steam.

Our experiment is to find out how many calories of heat are given out by one gram of steam in condensing to boiling water, and this number of calories is the same as that necessary to vaporize one gram of boiling water, without changing the temperature. This number of calories is called the *heat of vaporization.*

Experimental:

The boiler is half filled with water and the burner lighted under it. While the water is coming to a boil, 400 $cm.^3$ of as cold water as possible are measured into the calorimeter. How many grams of water are there? The *water equivalent* of the calorimeter, or the number of grams which must be added to the actual mass of the water to allow for the heating of the calorimeter, will be given by the instructor, or calculated under his direction.

In passing the steam from the boiler to the calorimeter, errors must be avoided by taking the precautions which follow. The steam must be free from water produced by condensation. A hot flame and the steam trap included in the apparatus, will help to secure this result. The temperature of the cold water is to be taken *immediately before* the steam is passed into it.

The delivery tube should dip far enough below the sur-

face of the water in the calorimeter for the steam to cause a rattle as it condenses. At all times the calorimeter should be shielded as far as possible from heat other than that of the steam passing into it.

The water should be constantly stirred with the thermometer, and its temperature watched. When it reaches about 40° C., the steam tube should be taken out, the

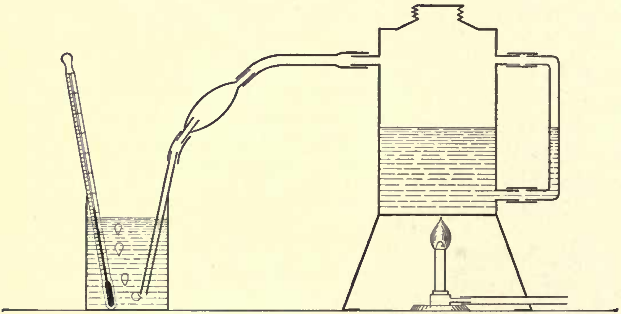

Fig. 80.

water stirred thoroughly, and the highest temperature reached after stirring should be recorded.

You know the number of grams of water with which you started. By measuring and recording the contents after the steam has passed, the mass of the steam may be calculated.

The observed results are to be placed in a table near the top of the left-hand page.

Observations

Volume of cold water	*cm.*^{3}
Final volume of water	*cm.*^{3}

Initial temperature of cold water and calorimeter	° *C.*
Final temperature of calorimeter and contents	° *C.*
Water equivalent of calorimeter	*g.*

A sectional drawing should be made to show the arrangement of apparatus and a brief description written, referring to the drawing. State the precautions that were taken to secure accurate results.

It is now possible to calculate the number of calories absorbed by the cold water, the number given out by the condensed steam in cooling, the number given out in condensing, and finally the heat per gram in condensing (heat of vaporization). These results should be entered in a table placed at the top of the right-hand page, the calculations being worked out immediately below.

CALCULATED RESULTS

Total cold mass (mass of water + water equivalent of calorimeter)	*g.*
Weight of steam condensed	*g.*
Change in temperature of cold water . . .	° *C.*
Change in temperature of hot water (condensed steam)	° *C.*
Calories absorbed by cold water in being warmed	*cal.*
Calories liberated by condensed steam in cooling to final temperature	*cal.*
Calories liberated by steam in condensing to water	*cal.*
Calories liberated by one gram of steam in condensing	*cal.*

Discussion:

What objection would there be in allowing drops of hot water condensed in the delivery tube to drop into the calo-

rimeter? What is meant by the heat of vaporization of a substance?

Conclusion:

The heat of vaporization of water, according to my determination, is ...... calories.

EXPERIMENT 64

Dew Point

OBJECT. To find the dew point at the temperature of the laboratory.

APPARATUS. Bright calorimeter; thermometer; two beakers; glass stirring rod; snow, or shaved ice; fine salt.

Introductory:

It has been found by experiment that warm air can contain much more water vapor than cold air. When a body of warm air saturated with water vapor meets a current of cold air, condensation occurs. Some of the water vapor appears as mist, fog, or rain. On a cool night after a hot summer day, the ground cools off quickly and chills the warm air laden with vapor, so that dew is deposited. The temperature to which the air must be cooled in order that condensation of water vapor may occur, is known as the *dew point*. This temperature depends upon the relative amount of water vapor in the air.

Experimental:

Place water to the depth of about an inch in a brightly polished calorimeter. In it stand a thermometer and a piece of glass tubing to serve as a stirring rod. Place

shaved ice or snow in one beaker and fill the other beaker with water.

(*a*) To the water in the calorimeter, slowly add a little ice at a time, stirring thoroughly after each addition. Continue until a *thin* film of moisture appears on the outside of the calorimeter. Note the temperature of the water in the calorimeter immediately on the appearance of the moisture. Avoid breathing on the calorimeter. *Why?*

A thick deposit of moisture indicates that you have cooled the water too rapidly and passed below the dew point. In such a case, add small portions of water from the other beaker and stir until the mist disappears. Then add ice very slowly until the dew point is reached.

If the air in the laboratory is very dry or quite cool, it may be necessary to add a little salt to the crushed ice in order to reach the dew point.

(*b*) Start with a thin film of moisture on the outside of the calorimeter, but have the vessel less than half full of the cooled water. Stirring all the time, note the temperature at which the moisture disappears. This temperature should be within a degree of that obtained in (*a*).

Observations

Temperature at which moisture appears . . . ° *C.*
Temperature at which moisture disappears . . ° *C.*

Make a simple drawing of your apparatus and describe the method briefly.

Take for the dew point the average of the temperatures at which the mist appears and disappears.

Discussion:

Just what air was cooled to its dew point in this determination? If the air in the room were nearly saturated

with water vapor, would the amount of cooling necessary to reach the dew point be small or great? Explain. How would you find the dew point of the outdoor air on a cold day?

Conclusion:

Define the dew point. Complete the following:

The dew point of the air in the laboratory at ----- on ----- was ----- °C.
(time)
(date)

EXPERIMENT 65

Magnetic Induction

OBJECT. To study the behavior of iron, steel, and other materials in a magnetic field.

APPARATUS. Strong bar magnet; pocket compass; small pieces of iron, copper, tin plate, granulated tin, nickel, pasteboard, glass; pieces of watch spring; sheets, at least 2 inches square, of pasteboard, glass, copper, iron, tin plate; blocks or other supports for magnet and compass; iron filings or small brads.

Introductory:

The most familiar property of a magnet is its ability to attract iron and steel. But when two magnets are brought near each other, only unlike poles attract, while like poles repel. A few simple tests of the behavior of iron and steel in a magnetic field will give the principal facts of magnetic induction. By this term we mean the production of magnetic properties in iron and steel by placing these materials in a magnetic field. Other materials will also be examined, to determine whether magnetic induction takes place in them as well.

Experimental:

(*a*) A magnet is successively brought near small pieces of iron, steel, copper, "tin" (sheet iron coated with tin), granulated tin, nickel, pasteboard, glass. Record in tabular form at the top of the left-hand page under the heading "Magnetic" the names of the materials attracted, and under "Non-magnetic," those not attracted.

(*b*) A piece of soft iron is held near a magnet, *but does not touch it.* Some iron filings or small brads are then brought in contact with the other end of the piece of iron. Note and record the result. Without jarring the iron, the magnet is then withdrawn carefully and the effect on the iron filings noted and recorded. The same test is made with a piece of hard steel (watch spring) in place of the soft iron, and the results noted.

(*c*) The tests in (*b*) are repeated with a magnetic needle instead of iron filings, and the results noted.

(*d*) Unmagnetized pieces of iron and steel are next stroked with a magnet in the manner directed by the instructor, and then tested with iron filings as in (*b*), and all results noted.

(*e*) The magnet and the compass needle are placed on convenient supports at such a distance apart as the instructor may direct. Sheets of pasteboard, glass, copper, iron, "tin" (iron coated with tin), are successively brought between the magnet and the needle, and the effect on the angle of deflection of the needle noted.

A brief description of each of the tests made should be written on the left-hand page of the note-book immediately after making the test, and the results, except in Part (*a*), should be written directly opposite on the right-hand page. The following table should be filled out for part (*a*).

Observations

Magnetic Substances	Non-Magnetic Substances
------	-----
------	-----

After all the observations have been recorded, the discussion should be written on the second right-hand page.

Discussion:

Compare the poles produced at the near and at the remote end of the induced magnet with the inducing pole of the permanent magnet. What reason have you for believing that there is a pole at the end of the iron near the inducing pole?

What effect does decreasing the distance between the iron and the magnet have on the strength of the induced poles? (Compare results in (*d*) with those in (*a*) and (*b*).)

Is the reading of a compass needle affected by the brass and glass case in which it is mounted? What material would you use to make a shield to protect a watch from becoming magnetized?

Conclusion:

(*a*) Explain, on the basis of the results obtained in this experiment, the attraction of a piece of iron or steel by a magnet.

(*b*) Compare iron and steel with respect to —

(1) the ease with which they may be magnetized;

(2) the permanence of the magnetization.

EXPERIMENT 66

Magnetic Lines of Force

OBJECT. To find the direction of the lines of force in certain magnetic fields.

APPARATUS. Two 6-inch bar magnets; 2-inch bar magnet (this may be replaced by one of the larger magnets); horseshoe magnet; cardboard; tin pepper box of iron filings, which have been heated to thoroughly dry them; two half-meter sticks or a board grooved to hold the magnets.

Introductory

If a piece of iron is placed in the neighborhood of a magnet, it is subject to a force proceeding from the magnet. This magnetic force acts in definite lines, called *lines of force*. When a magnetic needle is brought into the field of a magnet, it always places itself tangent to a line of force. Iron filings, when brought into a magnetic field and allowed to move freely, become tiny magnetic needles and so arrange themselves along lines of force. By covering a magnet with a piece of cardboard and sifting filings lightly over the cardboard, then tapping the cardboard gently, we allow the filings to move freely into position along the lines of force in the part of the field occupied by the cardboard.

Experimental:

The outlines of the magnets, as shown in Figs. 81 and 82, should be drawn in your book before you come to the laboratory, in order that the magnetic field in each case may be recorded promptly.

(*a*) Lay the bar magnet on the table and place the cardboard over it, using the half-meter sticks as supports.

Sprinkle iron filings lightly on the cardboard with the sifter held at some distance above the table. Tap the cardboard gently to permit the filings to arrange themselves. When a distinct representation of the magnetic field is obtained, make an outline drawing of it in the upper half of the right-hand page of your note-book. Be sure that your drawing shows the location of the definite lines of force along which the iron filings arrange themselves. Draw a few lines only to show the general shape of the field, and do not try to represent all the filings.

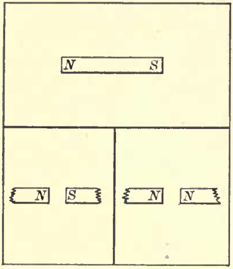

Fig. 81. First Right-hand Page.

(*b*) Slide the filings from the cardboard on to a sheet of paper and return them to the shaker. Arrange the two bar magnets with their unlike poles facing each other and about 3 cm. apart. Secure a map of the magnetic field on cardboard with iron filings as before, and sketch in the lower left corner of the right-hand page.

(*c*) In a similar manner, map the field between two like poles and record in the other corner of the right-hand page.

(*d*) Place the small magnet at right angles to one end of one of the large magnets and about 3 cm. distant. Map the field as before, and make a drawing of it in the upper half of the next left-hand page.

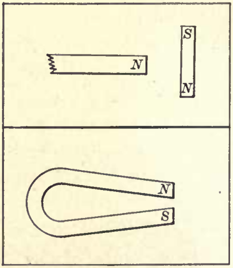

Fig. 82. Second Left-hand Page.

(*e*) Map the field in the vicinity of the poles of a horseshoe magnet, representing it in the lower half of the second left-hand page.

Write a brief description of the method employed to map the fields. No other drawing is necessary.

Conclusion:

Do opposite poles seem to be drawn together or pushed apart? What is the effect with like poles? What special advantage is there in the horseshoe-shaped magnet?

EXPERIMENT 67

Development of an Electrostatic Series

OBJECT. **To arrange various substances in such an order that each will be positively electrified when rubbed with the substance following it in the series and negatively electrified by the preceding substance.**

APPARATUS. Gold-leaf electroscope;[1] four blocks of wood with hard rubber handles, having the following substances cemented to them: a sheet of glass, a sheet of hard rubber, a piece of silk, a piece of cat's fur.

CAUTION. All the above substances must be thoroughly dry and, if possible, warm when they are used. They should be carefully tested before the laboratory period, to determine that they are in a non-conducting condition. If atmospheric conditions are bad, the experiment should not be attempted.

Introductory:

The attraction of light objects by rubbed amber was the first electrical experiment ever made. The behavior of electric charges was investigated quite thoroughly before current electricity was produced, and modern

[1] A convenient electroscope is shown in Fig. 83. An 8-oz. wide-mouth bottle has a strip of tin foil fastened with shellac across the bottom outside, up one side, and through the neck of the bottle down the same side within, across the bottom and up the other inside face of the bottle to the bottom of the neck. In this way the electroscope can be thoroughly grounded and danger of overcharging avoided. The rod of the electroscope is of $\frac{1}{8}''$ brass, bent into a flat square at the top, as shown in Fig. 84 and filed to a double bevel at the bottom. This rod is passed through the opening of a one-hole rubber stopper to such a distance that it will reach to about the middle of the bottle, and the hole is then filled with melted sulphur, to better insulate the rod. A gold leaf, about an inch long, is then attached with shellac to each of the beveled surfaces. The stopper, with the rod and leaves, is then inserted in the neck of the bottle, care being taken not to break the tinfoil on the side of the neck.

theories of electricity have a great deal to say about electric charges. As a matter of agreement among scientists, the charge produced on glass, when rubbed with silk, is called *positive* (+); that produced on sealing wax, when rubbed with flannel, is *negative* (−). These are only relative terms. In our experiment we shall seek to establish a graduated series, with the most positive at the top and the most negative at the bottom.

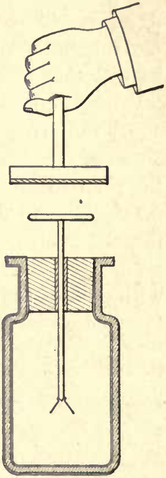

Fig. 83.

Experimental:

The electroscope is charged positively by induction, using the hard rubber plate rubbed with the cat's fur. The hard rubber plate after it is negatively charged by the cat's fur, is again brought down carefully from above to within a centimeter of the top of the electroscope and its effect on the divergence of the leaves noted. A similar test is made with the positively charged fur. The effect of each of these charged bodies on the divergence of the leaves should be recorded, as these results are the standard with which we shall compare the results obtained with the other pairs of substances tested. In the table record fur as + and hard rubber as −.

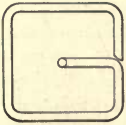

Fig. 84.

The charge on the hard rubber plate is then removed by holding the finger at one edge and breathing across the surface, or by passing the plate quickly through a flame. If there is no effect, or only a very slight one, when the plate is

again brought near the electroscope, the plate may be considered as discharged. Each plate must be similarly discharged, before being rubbed with a new substance. The flame should not be used with the fur.

After both the glass and the hard rubber have shown by test that they have no charge, they are to be rubbed together and each in turn brought down carefully from above near the top of the electroscope. From the results obtained, record this pair in the table, giving each charge the proper sign.

Continue to discharge two substances, then rub them together, and finally determine the sign of the charge on each, until each of the four substances has been rubbed with each of the others. Record all results in the tabular form, near the top of the left-hand page.

Observations

Charge	*Pairs of substances tested:*				
+	*Cat's fur*	-----	-----	-----	etc.
–	*Hard rubber*	-----	-----	-----	etc.

A careful description of the method of charging the electroscope and of the effect on the charged electroscope of the fur and hard rubber should be given, accompanied by a simple sectional drawing of the electroscope and one of the plates under test, with the charge on the plate and on the electroscope marked.

Place on the right-hand page the following tabular form.

Summary of Results

Substance	Number of Times Positive	Number of Times Negative
-----	-----	-----
-----	-----	-----
-----	-----	-----
-----	-----	-----

Conclusion:

From the summary of results, arrange the substances in a vertical series, with the one positive the greatest number of times at the top, the next most positive next, and so on. If you find that your series, as thus arranged, fulfills the conditions stated in the Object, place a + sign above and a – sign below the column and make a statement to the effect that this is the correct arrangement of the series.

EXPERIMENT 68

The Simple Cell

OBJECT. To study the chemical and electrical action in a simple voltaic cell.

APPARATUS. Tumbler of sulphuric acid (1 : 20); strips of amalgamated and unamalgamated zinc; strip of copper; galvanometer or low-reading voltmeter;[1] battery stand or clamps for holding elements in place; No. 18 insulated copper wire for connections.

Introductory:

When two conductors are placed in a solution which acts on one of them more than on the other, a difference

[1] It is the belief of the authors that voltmeters and ammeters are to be preferred to galvanometers, as they introduce the student directly to practical units. High-grade commercial instruments of the d'Arsonval type may now be had at prices which make the original investment but little more than that for galvanometers, while the trouble and expense of keeping galvanometers in order is far more than for the commercial instruments. Ammeters should have external shunts; the instrument movement without the shunt may then be used as a galvanometer in Wheatstone bridge and induction experiments. The scales recommended for the ammeters are 12 amperes and 1.2 amperes. The voltmeters should have 120 volt and 6 volt scales. Where voltmeters are not available, d'Arsonval galvanometers may be used in many experiments. Tangent galvanometers, or shunted d'Arsonval instruments, may be substituted for ammeters.

of potential is produced between the two conductors. When they are joined by a wire, an electric current flows from one to the other. A strip of zinc and a strip of copper immersed in dilute sulphuric acid constitute a simple cell. We wish to investigate the chemical and electrical action that takes place in such a cell.

Experimental:

A strip of zinc and one of copper, a tumbler containing dilute sulphuric acid, clamps for holding the strips in place, connecting wires, and a voltmeter will be furnished you. The chemical action on the strips is tested by placing each in the acid separately, then both together, first unconnected and then connected (Observations 1–4). The relative number of bubbles produced at each plate should be noted and recorded in Observations 1–5.

The order of operations is indicated in the table of observations, to which the numbers in the text refer. Where there is not room to write the observed result on the left-hand page, it may be continued on the same line of the right-hand page.

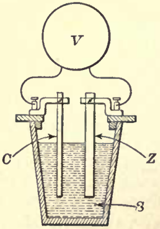

Fig. 85.

Amalgamated zinc (zinc coated with mercury) is next substituted for the plain zinc and connected by a wire with the copper (Observation 5). A wire from each plate is separately touched to the tongue (Observation 6), and then both wires are touched to the tongue at different points (Observation 7).

The wires are connected to a voltmeter. When the needle swings over the scale in a positive direction, the current leaves the cell by the wire connected to the plus

terminal of the voltmeter. The terminal of the cell to which this wire is connected is the plus electrode, or *cathode*. Read the deflection if the needle is on the scale. Reverse the connections at the voltmeter and determine whether the current has a definite direction (Observations 8, 9, 10).

Observations	Results
1. *Copper in acid*	
2. *Zinc in acid*	
3. *Both in acid, unconnected* . . .	
4. *Both in acid, connected* . . .	
5. *Zinc amalgamated, connected to copper*	
6. *Each wire touched to tongue separately*	
7. *Both wires touched to tongue*	
8. *Copper connected to voltmeter +, reading*	
9. *Zinc connected to voltmeter +, reading*	
10. *Cathode (+) plate of cell is*	

Make a drawing of the stand, the tumbler, and the plates, in the usual place on the left-hand page, and include in your description any points not noted in the table.

Explanation of the Chemical Action.—(Not to be written in the note-book.) The production of gas in the liquid shows that chemical action is going on. The gas is hydrogen, and results from the decomposition of the acid. The remainder of the acid unites with the zinc,

forming a soluble compound. The action of the acid on the zinc, when the plates are not connected, is called *local action.* The deflection of the voltmeter corresponds to the electric pressure. A loss of electric pressure after the cell has been in action for some time is due to *polarization.*

Discussion:

How is local action prevented or diminished? Why is it desirable to prevent it? Give two ways of showing the passage of a small current through a wire. Which test might furnish a method of determining the direction of the current flow? How?

Conclusion:

State the essential parts of a simple cell.

EXPERIMENT 69

The Two-fluid Cell

OBJECT. To study the prevention of polarization in the Daniell cell.

APPARATUS. Tumbler; porous cup; battery stand; amalgamated zinc; copper strip; voltmeter or high resistance galvanometer; resistance box, or coil of wire having a resistance of about 20 ohms; # 18 insulated copper wire.

MATERIAL. Dilute sulphuric acid (1:20); saturated solution of copper sulphate.

Introductory:

When the push button of a doorbell is pressed for a long time, the bell will often stop ringing. A change has taken place in the battery which prevents a current sufficient

to ring the bell from passing. This change is an increase in resistance and a decrease in the difference in potential between the plates of the cell; it is called *polarization.* We are going to observe the polarization of a simple cell, and see how it is prevented in a two-fluid cell, called the Daniell cell.

Experimental:

(*a*) A simple cell is set up as in Experiment 68. The difference of potential of the freshly prepared cell is read by means of a voltmeter. The cell is then allowed to send a current through a coil of wire connected to its terminals, and the voltage is read immediately after connecting the coil. The difference between this and the first reading is due to the fact that only the part of the pressure which is driving the current through the coil is now being measured. The voltmeter is carefully watched until the needle becomes stationary, when a reading is taken. Any difference between the second and third reading is due to polarization.

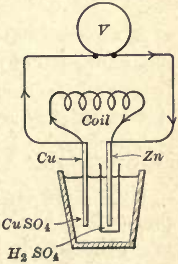

Fig. 86.

Notice whether there are hydrogen bubbles on the copper plate. Record result. If bubbles are noticed, rub them off with the finger, and again observe the voltmeter reading.

(*b*) Part of the acid is poured into a small porous cup. This is set into the tumbler containing the remainder of the acid. The plates are then inserted, the zinc into the acid in the porous cup and the copper into the acid in the tumbler. The voltage is read before connecting the coil, immediately after connecting the coil, and when the needle becomes stationary, as in (*a*). *Does the porous cup*

prevent polarization? Notice whether bubbles form, as in (*a*).

(*c*) Keeping sulphuric acid in the porous cup around the zinc, replace the acid in the tumbler with copper sulphate solution. The cell now has zinc in sulphuric acid and copper in copper sulphate, and is known as a Daniell cell (Fig. 86). Make three readings of voltage, under the same conditions as in the preceding parts of the experiment. *Does the copper sulphate prevent polarization?*

Record the results of your observations in tabular form near the top of the left-hand page.

OBSERVATIONS

	PART (*a*)	PART (*b*)	PART (*c*)
Bubbles appear at . . .	------	------	------
Voltage before closing circuit	------	------	------
Voltage, circuit just closed	------	------	------
Voltage, needle stationary.	------	------	------

A diagrammatic sketch, similar to Fig. 86, should be made for each of the three tests. In each sketch, label each plate and the contents of the tumbler and the porous cup. A very brief description should accompany these drawings.

Discussion:

How does the collection of hydrogen on the copper plate affect the voltage of the cell? Which is more practical, the simple cell or the Daniell cell? Why?

Answer also the questions in italics occurring in the experimental directions.

Conclusion:

What prevents polarization in the Daniell cell?

EXPERIMENT 70

Electroplating

OBJECT. To electroplate (*a*) with copper; (*b*) with nickel.

APPARATUS. Porcelain battery top, or Skidmore battery stand; electric light carbon; copper sheet 4″ × 2″, with wire attached; strip of pure nickel about 3″ × 1″; two storage cells, or three Daniell cells; two tumblers; wire for connections; reversing switch (Fig. 88) is desirable.

MATERIAL. Saturated solution of copper sulphate; plating bath of nickel ammonium sulphate;[1] rouge cloth or other polishing material.

Introductory;

The simplest and most convenient method of plating an object is by means of the electric current. The positively charged metallic ions travel with the current and deposit at one electrode. The object to be plated should be an electrode in a solution of some compound of the metal to be deposited. If a current of suitable strength is then passed, a film of the metal coats the object. To supply the place in the solution of the metallic ions deposited, a strip or bar of the plating metal is hung in the solution and serves as the other electrode. If the object to be plated is an insulator, it must first be coated with some conducting material, such as graphite. An object to be nickel plated is usually copper plated first; the nickel is then plated on the copper coating.

[1] This solution is made by dissolving in one liter of water, 72 g. of nickel ammonium sulphate, 23 g. of ammonium sulphate, and 5 g. of crystallized citric acid. Then ammonium hydroxide is added until the solution is no more than slightly acid to blue litmus. If, after some time, the solution does not plate well, more ammonium sulphate should be added. The bath should always have a slightly acid reaction.

Experimental:

(*a*) *Copper Plating.* — Fasten an electric light carbon in one clamp, and the wire attached to a copper strip in the other clamp of the stand or battery top furnished you. The copper should be bent into cylindrical form, encircling the carbon, but not touching it at any point (Fig. 87). Immerse the carbon and the copper in a tumbler of copper sulphate solution. Is there any action?

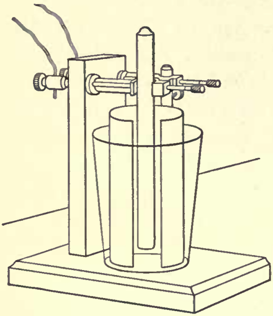

Fig. 87.

Connect the copper terminal with the positive terminal of two storage cells (or three Daniell cells), connected in series. Allow the current to pass for five minutes. Withdraw both the carbon and the copper and examine them.

Replace them in the solution, reverse the direction of the current through the plating cell, and leave them for five minutes. Again examine.

Decide upon the correct connection for plating the carbon and allow the current to pass long enough to form a firm deposit. When the carbon is well coated, take it out of the solution and allow it to dry; then polish it with rouge cloth.

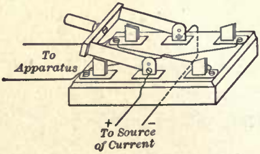

Fig. 88. Reversing Switch.

Which arrangement of the carbon and copper is correct? Why? Upon which terminal, anode or cathode, is the metal

deposited? Where did the deposited metal come from? What is the use of the copper strip?

(*b*) *Nickel Plating.* — Wash all the copper sulphate solution from the clamps for holding the electrodes. Fasten the copper-plated carbon and a strip of nickel in the two clamps. Immerse the electrodes in a tumbler of nickel ammonium sulphate solution. Pass the current, making the nickel the anode, for five minutes, noting the action. The pressure should be about 2.2 volts. When a good coating of nickel is obtained, remove the cathode from the solution and examine it. Compare the thickness of the coating on the side near the nickel electrode with the coating on the other side. When dry, polish with rouge cloth.

Would it be better if the nickel anode surrounded the carbon, as the copper anode did?

Make a simple diagram, showing the parts of the plating cell, and the direction of the current when plating occurs. Also indicate the source of current. With reference to the diagram, describe the operations in (*a*) and (*b*), giving the results in each case.

Discussion:

Under this heading on the right-hand page, answer the questions occurring in the experimental directions.

Conclusion:

Complete the following statement:

In electroplating, the object to be plated is the -----, the plating metal is the -----, the solution furnishes -----.

EXPERIMENT 71

Electrotyping

OBJECT. **To make a small electrotype.**

APPARATUS. Skidmore stand or porcelain battery top; copper strip $1'' \times 5''$; lead strip $1'' \times 5''$; tumbler; beaker; three Daniell cells;[1] wire for connections; small brush; Bunsen burner; pieces of type or seals.

MATERIAL. Powdered graphite; beeswax; saturated solution of copper sulphate; 5 per cent solution of zinc sulphate; pieces of cloth.

Introductory:

A printer in his smaller job work prints the copies from the type set up by the compositor. When the number of copies desired runs up into the thousands, as in a large edition of a book, the type metal is not hard and durable enough to give such a large number of clean-cut impressions. Accordingly a wax impression is made of the type as set. The wax impression, covered with a conducting material, as graphite, is then electroplated with copper. The thin coating of copper, which has taken the form of the wax mold, is stripped from the wax, backed with some easily fusible metal, and mounted on a wooden block. In this way an electrotype is made with a hard surface of copper in the form of the original type.

Experimental:

Hold the strip horizontally above a small Bunsen flame, so that some pieces of beeswax, placed on the upper sur-

[1] As the Daniell cells are run over night, the zinc plates should be well amalgamated and a 5 per cent solution of zinc sulphate be used instead of sulphuric acid. When not in use, short-circuit these cells.

face of the strip, will melt and cover uniformly two thirds of the strip with a coating about $\frac{1}{8}$ inch thick (Fig. 89).

When the wax has cooled and hardened, rub with a cloth finely powdered graphite over the wax and beyond it to the surface of the lead, in order to prepare a conducting surface. Enough graphite should be used to make a firm, shiny coating.

Take the type or other object to be copied and rub graphite over its surface. Then press the type into the wax, until a clean-cut impression extends nearly but not quite through the wax, when the type is removed. Dust the impression again with graphite, taking care not to mar the outline.

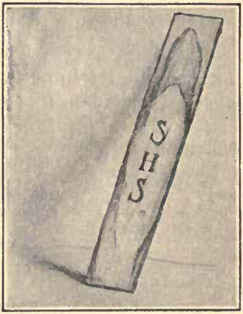

Fig. 89.

With a brush and melted beeswax, coat the back and edges of the lead strip up to the point where it is to be clamped.

Clamp the lead and copper strips in place, so that the impression is toward the copper strip. Immerse the strips in a tumbler of copper sulphate solution. The electrodes should be about one centimeter apart. Arrange three Daniell cells in series and connect them with the electrodes in the plating solution, making the copper the anode. After the current has been running for five minutes, remove and examine the lead strip. Coat with melted wax any place where copper has been deposited outside of the impression which you wish to copy.

Return the electrode to the solution and allow the current to pass until the laboratory period next day.

At the next laboratory period, remove and wash off the

lead strip. Immerse it in hot water so as to soften the wax, and then with the aid of a knife strip off the deposited copper carefully in one piece. The last pieces of adhering wax may be removed by heating the copper and wiping it with a cloth.

Back the copper with melted tin to the thickness of $\frac{1}{8}$ of an inch, in case the instructor gives directions for so doing. Otherwise put the electrotype in an envelope and attach the envelope to the note-book page by the flap.

Make a diagram showing the arrangement of the apparatus and a drawing showing the lead strip with its coating and impression. Describe the experimental method with references to these drawings.

Discussion:

What was the use of the copper strip? Of the lead strip? Why was the current allowed to run all night?

EXPERIMENT 72

The Storage Cell

OBJECT. To study the construction and action of a simple storage cell.

APPARATUS. Tumbler; two lead plates, about $3'' \times 1''$; Skidmore or other battery clamp; voltmeter or galvanometer; electric bell; # 18 insulated copper wire for connections.

MATERIAL. Sulphuric acid (1 of acid to 8 of water); sandpaper.

Introductory:

The essential conditions for the production of a voltaic cell are two different plates and a solution that will react

chemically with one of them more than with the other. The limit to the usefulness of such a cell is reached when one of the plates or the electrolyte is used up. This fact makes the primary cell a very expensive source of current. In the lead secondary or storage cell, this difficulty is avoided. The two plates of this cell are alike before "charging." The cell is charged by passing a current through the plates and the electrolyte. The latter is decomposed and the products of decomposition add oxygen to one plate and take oxygen from the other, thus making the plates different chemically. When the cell is used as a source of current, a reverse action takes place — the plates again becoming alike and the electrolyte being restored to its original form. This process can be repeated a great many times before it is necessary to put in new plates.

Experimental:

(*a*) The lead plates are to be thoroughly cleaned with sandpaper until the surface is bright. Then set the plates in a tumbler of dilute sulphuric acid and clamp them so they will not make electrical contact with each other. Connect the plates to a voltmeter or galvanometer. *Is there any difference of potential between the lead plates when immersed in sulphuric acid?*

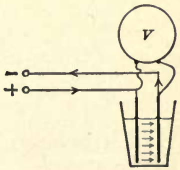

Fig. 90. Cell Charging.

(*b*) Without disconnecting the voltmeter, connect the two plates with a source of current having a pressure of about 4 volts. Reverse the connections of the meter, if necessary, so that the needle remains on the scale. Note the reading of the meter and record. Observe also whether bubbles collect at either or both plates. If at

both plates, at which are they produced more freely, anode or cathode? Pass the current for two minutes, then disconnect the source of current. Observe and record any deflection of the meter when the current is no longer passing into the cell from an outside source. Short-circuit the cell, by connecting the plates with a wire, for a minute or so. Disconnect the short-circuiting wire and again read the meter.

(*c*) Again charge the cell, this time for from 5 to 10 minutes. At the end of the charge take the meter reading, as before. *Is the plate which is the anode when charging, the anode or cathode when discharging?*

Remove the plates and observe any change in appearance that has taken place. Replace the plates and connect them to an electric bell. Result? By short-circuiting the cell, bring it back to an uncharged condition, as shown by the meter.

Most of the observations made can be recorded by filling in the proper spaces in the following tabular form to be placed near the top of the left-hand page.

Observations

	Before Charging	While Charging	Fully Charged	Discharged
Voltmeter reading. . .	-----	-----	-----	-----
Bubbles at anode . . .	——	-----	——	——
Bubbles at cathode . .	——	-----	——	——
Color of anode	-----	——	-----	-----
Color of cathode . . .	-----	——	-----	-----

Note. In the table fill in spaces marked (-----), but leave blank spaces marked (——).

Make a diagrammatic sketch showing the connections of the apparatus and write a brief statement of the steps of the experiment. Include in the description any observed facts not already noted in the table.

Discussion:

Lead peroxide is chocolate colored. Which plate, the lead or the lead peroxide, is the positive plate when the cell is charged? Does the cell store electricity or chemical energy which can be converted into electricity?

Conclusion:

State the action which takes place in charging and in discharging a storage cell.

EXPERIMENT 73

Laws of Resistance

OBJECT. To determine how the resistance of a wire is related to its length, area of cross section, and material.

APPARATUS. Resistance board, on which are stretched the following wires, connected in series: 2 meters # 28 copper; 2 meters # 28 copper; 2 meters # 22 copper; 4 meters # 28 iron; battery furnishing about 6 volts; low-range voltmeter and ammeter, or d'Arsonval and tangent galvanometers; # 18 insulated wire for connections.

Introductory:

There is a difference in the filaments of a 16 candle power lamp and a 32 candle power lamp, made for use at the same voltage. The filament of the more powerful light allows about twice as much current to pass as the 16

candle power filament does. This difference in current is due to a difference in the resistance of the two filaments. The difference in resistance is secured by making the filament of different dimensions. With the same number of volts applied, a copper wire will permit a greater current to pass than a German silver wire of the same dimensions. Here it is the material that makes the difference in resistance. By experimenting with wires of known lengths, areas, and materials, the effect of each of these on the resistance of the wire may be determined.

Experimental:

The wires to be tested are mounted on a board, provided with binding posts at the end of each wire. By connecting a battery to the two outside binding posts, a current is

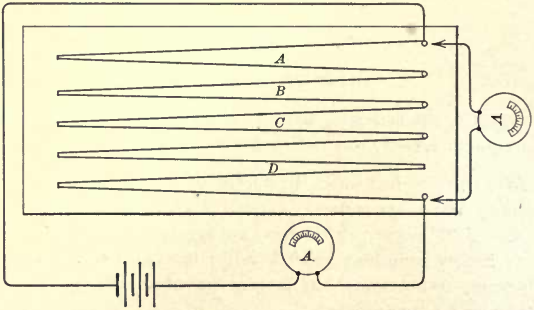

Fig. 91. *A*, 2 meters copper #28; *B*, 2 meters copper #28; *C*, 2 meters copper #22; *D* 4 meters iron #28.

sent through the wires in series. In order to read the value of the current, an ammeter is inserted between the battery and the resistance board. A voltmeter is provided with wires which can be connected to any pair of binding

posts (Fig. 91). The length in meters of each wire and its area in circular mils will be marked on the board or may be measured. A *circular mil* is a circle whose diameter is one one-thousandth of an inch. The area of # 28 wire is approximately 160 circular mils and the area of # 22 wire is approximately 640 circular mils.

After the connections have been made as just described, the current through the wire and the drop of potential between the ends are read and recorded in each of the following instances :

(*a*) 2 meters of # 28 copper wire.
(*b*) 4 meters of # 28 copper wire.
(*c*) 2 meters of # 22 copper wire.
(*d*) 4 meters of # 28 iron wire.

Observations

Trial	Length of Wire	Area of Wire	Material	Current	Pressure
a	m.	c.m.	copper	amp.	v.
b	m.	c.m.	copper	amp.	v.
c	m.	c.m.	copper	amp.	v.
d	m.	c.m.	iron	amp.	v.

A diagram should be made showing the connections of the apparatus, and a brief description of the method of the experiment should follow the table of observations.

By comparing the results of (*a*) and (*b*) the effect of length on resistance may be obtained ; (*a*) and (*c*) will show the effect of area of cross section. The resistances obtained in (*b*) and (*d*) will show the comparative resistances of copper and iron. The resistances may be calculated by the application of Ohm's Law.

Calculated Results

Trial	*a*	*b*	*c*	*d*
Kind of wire				
Resistance				

Discussion:

Explain the method of calculating the resistance of the wires.

Conclusion:

State the relation between the resistance of a conductor and its length; the relation between the resistance and the area of cross section.

How many times is the resistance of iron as great as that of copper?

EXPERIMENT 74

Effect of Temperature on Resistance

OBJECT. To observe the change in resistance of various conductors with a change in temperature.

Apparatus. Coil of iron wire, wound on a porcelain insulating tube;[1] similar coils of German silver wire and of some wire of very low temperature coefficient, such as manganin, or "Ia Ia"; ammeter, or low resistance galvanometer; iron tripod for supporting coils; Bunsen burner with wing top; wire for connections; 3 storage cells.

[1] The porcelain insulating tubes can be obtained from any dealer in electrical supplies; binding posts are mounted on the ends of wooden plugs inserted in the ends of the tube, and the wire, wound tightly around the porcelain, is clamped between the binding post and the wood. (Fig. 92.) Ia Ia wire can be purchased of H. Boker and Co., 101 Duane St., N.Y.; manganin wire is sold by the Central Scientific Co., Chicago.

Introductory:

The temperature of the conductors in the field and in the armature of a dynamo is higher than that of the surrounding air when the machine is running at full load. Will they have the same resistance as at ordinary temperatures? Can we, by measuring the resistance of a cold incandescent lamp, determine how much current the lamp would take at the voltage necessary to make the lamp glow brightly? Do all conductors behave alike with regard to the effect of temperature on their resistance? These are some of the questions which this experiment is designed to answer.

Fig. 92. Coil wound on Tube.

Experimental:

(*a*) Support the coil of iron wire on a tripod, in such a way that a considerable part can be heated. Arrange a circuit having the coil of iron wire, the battery and the ammeter in series. Observe and record the reading of the ammeter. Place the lighted burner under the central part of the coil and take another reading of the ammeter when the coil becomes red-hot (Fig. 93).

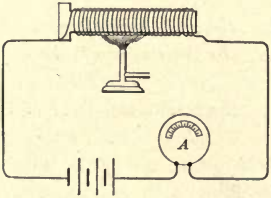

Fig. 93.

(*b*) Using the same source of current, read the current through the coil of German silver wire, cold and hot.

(*c*) Take the same readings with the coil of special resistance wire, the name of which will be given you by the instructor.[1]

[1] If it is desired to extend the experiment to carbon, the resistance of an incandescent lamp can be found when cold, by means of a Wheatstone

Observations

Trial	Material	Temperature (Hot or Cold)	Current
a	Iron	Cold	...... amp.
a	Iron	Hot	...... amp.
b	German silver	Cold	..... amp.
b	German silver	Hot	...... amp.
c	......	Cold	...... amp.
c	......	Hot	..... amp.

Make a simple drawing, showing one of the coils being heated, with the ammeter and battery connected in circuit. A brief description of the experiment should accompany the drawing.

Record in tabular form, at the top of the right-hand page, whether the resistance of each material is increased or decreased by an increase of temperature. Remember that, with the same voltage applied, an increase in current means a decrease in resistance.

Deductions

An increase of temperature ..... the resistance of iron.

An increase of temperature ...... the resistance of German silver.

An increase of temperature ...... the resistance of .....

Discussion:

Metals in general behave like iron.

Account for the fact that a tungsten lamp takes several times as much current at the instant when the current is turned on as it does a few seconds later. Why is the

bridge; and then at normal voltage by the voltmeter and ammeter method. If this is done, the results should be recorded in a separate table.

special resistance wire which you have tested better for use in a resistance box than German silver?

Conclusion:

What is the effect of an increase in temperature on the resistance of most metals?

EXPERIMENT 75

Internal Resistance of a Cell

OBJECT. To determine the effect of the size of the plates and the distance between them on the internal resistance of a cell.

APPARATUS. Tumbler; porous cup; amalgamated zinc; copper plate; porcelain top for holding plates so that their distance can be varied; voltmeter; ammeter; # 18 insulated copper wire for connections.

MATERIAL. Dilute sulphuric acid (1:20); copper sulphate solution.

Introductory:

Dry cells and other cells are made in different sizes. It is natural to suppose that there is some difference in the performance of one of the three tiny cells contained in a pocket flash lamp, and one of the large dry cells used for ignition in an automobile. By using a cell in which the area of the plates immersed and the distance between them can be varied, we can determine what effect the size and distance of the plates has on the voltage and on the amperage of the cell.

Experimental:

From the materials furnished you, assemble a Daniell cell. The distance between the plates of your cell may be

varied by moving the clamps which hold the plates toward or away from each other. This will change the *length* of the liquid conductor by which the current flows through the cell, without changing its cross section. The *cross section* of the liquid conductor depends upon the area of the plates immersed in the electrolytes, and may be changed without varying the length. The *materials* of the conductor remain unchanged throughout.

Except when taking readings, keep the circuit open. The terminals of the cell should be connected to one instrument only at a time, and not to both.

(1) Immerse the plates as far as possible, and bring them as near together as the walls of the porous cup will permit. Read the voltmeter and ammeter separately and record in the table of observations.

(2) Separate the plates as far as the walls of the tumbler will permit. Take and record the reading of each instrument.

(3) Keeping the plates at the same distance as in (2), raise them until the plates project only 1 cm. into the liquids. Read and record as before.

Observations

Trial	Position of Plates	Length of Plates Immersed	Volts	Amperes
1	Close	Entire	-----	-----
2	Separated	Entire	-----	-----
3	Separated	1 cm.	-----	-----

Make simple sectional drawings of the cell, showing the position of the plates and the amount immersed for each case. A very brief description should accompany these drawings.

Discussion:

Does the electromotive force of the cell depend upon the materials or upon the length of the liquid conductor? Upon what conditions does the current furnished depend? Will a large Daniell cell have a higher electromotive force than a small one? Will it furnish more current?

Conclusion:

Applying Ohm's Law, state how the resistance of a cell is affected by the size of the plates and by the distance between them.

EXPERIMENT 76

Grouping of Cells

OBJECT. To determine the proper connection of two cells to secure the greatest current, (*a*) when the external resistance is low; (*b*) when the external resistance is high.

APPARATUS. Two student's Daniell cells, tumbler form; resistance box; connection board, with switches and connections as shown in Fig. 94 (double connectors may be substituted for switches if necessary); ammeter.

Introductory:

If two like pumps are placed side by side, drawing water from the same reservoir and delivering into the same pipe, the two pumps will deliver twice as much water as one pump can deliver, but at the same pressure. These pumps may be said to be *in parallel.* If, however, the two pumps were so placed that the second took its water from a pipe to which it had been delivered by the first, the amount of water delivered would be no greater than

that delivered by one pump, but the pressure of the water would be twice as great. These pumps may be spoken of as *in series.*

Voltaic cells may be arranged either in parallel or in series. The arrangement which will yield the greater current depends upon the external resistance, as compared with the combined resistance of the cells. By using a low external resistance and a high external resistance, with the cells connected in each of the two ways, a general conclusion may be reached.

Experimental :

(*a*) Two small-sized Daniell cells are set up. By the use of a combination of switches, as shown in Fig. 94, or by the use of simple connecting wires, the zinc of one cell is connected to the copper of the other. The resistance box and the ammeter are connected in series with the two remaining terminals. After making the connections, inspect them to see that all the current must pass through each part of the circuit ; this is the test of a *series* connection. Withdraw the 0.2-ohm plug from the resistance box. Read the ammeter and record in the table of observations placed near the top of the left-hand page.

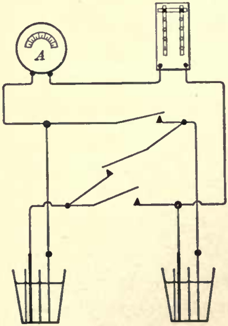

Fig. 94.

Replace the 0.2-ohm plug, and, without changing connections, remove the 20-ohm plug. Read the ammeter and record.

(*b*) Connect the two copper plates and connect the two zinc plates. To the combined copper terminal connect

the + terminal of the ammeter, and then connect the resistance box between the other terminal of the ammeter and the combined zinc terminal of the cells. Be sure that the coppers of the cells have no other connection with the zincs, except through the ammeter and resistance box. The cells are now connected *in parallel* with each other and are sending a current through the resistance box, and the same current through the ammeter. Take readings through the 0.2-ohm coil and through the 20-ohm coil, and record, as in (*a*).

Observations

Connection of Cells	Series	Series	Parallel	Parallel
Resistance	______ *ohms*	______ *ohms*	______ *ohms*	______ *ohms*
Current	______ *amp.*	______ *amp.*	______ *amp.*	______ *amp.*

Make two connection diagrams, one showing the cells in series connected with the resistance box and ammeter, and the other showing the cells in parallel connected with the resistance box and ammeter. A brief description should accompany the diagrams.

Discussion:

As the resistance of electrical apparatus is in general much higher than the battery furnishing the current would have in either arrangement, which will be the usual method of connecting voltaic cells?

Conclusion:

With what kind of external resistance do cells in parallel furnish the greater current? With what kind of external resistance are cells in series better?

EXPERIMENT 77

Resistance and Current in a Divided Circuit

OBJECT. To compare, (*a*) the currents in the branches of a divided circuit with the resistance of those branches; (*b*) the total resistance with the resistance of the branches.

APPARATUS. Lamp board like that shown in Fig. 95[1]; 32 candle power lamps to fill board; 3 ammeters; voltmeter, with connecting wires; connections to 110 volt D.C. circuit.

Introductory:

In the shunt dynamo the current generated in the armature divides, part of it passing through the coils of the field magnet, and the remainder passing out to the external circuit. In the most common type of ammeter, nearly all the current passes through a shunt, connected across the terminals of the galvanometer movement, and only a small fraction passes through the movement itself. In these and other cases of divided circuits, or shunts, two questions arise: How does the current divide between the two paths? What is the combined resistance of the paths?

Experimental:

Proper connections for a circuit of two branches, like that shown in Fig. 95, are to be made. The resistance in

[1] The lamps may be replaced by resistance boxes and the ammeters by tangent galvanometers, if only part (*a*) of the object of the experiment is to be worked out.

each branch of the circuit consists of an equal number of similar incandescent lamps, connected in parallel. The ammeters are so connected that the total current through both branches can be read and also the individual current in each branch. The terminals of a voltmeter, which is not shown, are to be connected to the terminals of any portion of the circuit whose resistance is desired.

All the lamps on both sides are to be turned on and reading of each ammeter recorded. The voltmeter is

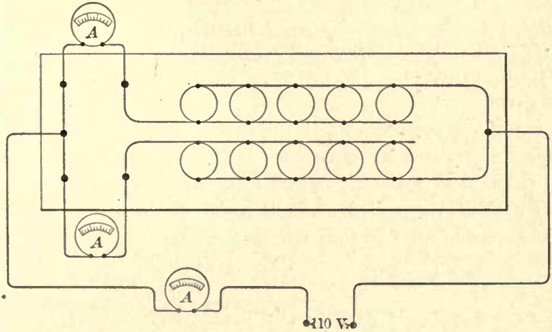

Fig. 95. Lamp Board, Ammeters, and Connections.

then connected in succession to the terminals of each branch circuit and to the terminals of the combined circuit and the readings obtained recorded in tabular form near the top of the left-hand page. All the lamps but one on one branch are then turned out, leaving all the lamps in the other branch of the circuit burning. Readings of the voltmeter and ammeters are taken and recorded as before. Make the following additional combinations in the two branches and record the results: 2 lamps and 3 lamps; 2 lamps and 4 lamps; 2 lamps and 5 lamps.

Observations

Branch A			Branch B			Total Circuit	
Lamps	Amperes	Volts	Lamps	Amperes	Volts	Amperes	Volts
5	-----	-----	5	-----	-----	-----	-----
5	-----	-----	1	-----	-----	-----	-----
2	-----	-----	3	-----	-----	-----	-----
2	-----	-----	4	-----	-----	-----	-----
2	-----	-----	5	-----	-----	-----	-----

A simple diagram of connections should be made, and a brief description of the method of making the tests should be given.

From the readings of the instruments the resistance of each branch and the resistance of the entire circuit should be calculated for each case, by the application of Ohm's Law. The reciprocal of each resistance obtained should also be calculated to four decimal places.

Calculated Results

Branch A

Lamps	5	5	2	2	2
Resistance (R_a)	-----	-----	-----	-----	-----
$\frac{1}{R_a}$	-----	-----	-----	-----	-----

Branch B

Lamps	5	1	3	4	5
Resistance (R_b)	-----	-----	-----	-----	-----
$\frac{1}{R_b}$	-----	-----	-----	-----	-----

Total Circuit Resistance (R)	-----	-----	-----	-----	-----
$\frac{1}{R}$	-----	-----	-----	-----	-----
$\frac{1}{R_a}+\frac{1}{R_b}$	-----	-----	-----	-----	-----

Discussion:

Does increasing the number of lamps in parallel in a circuit increase or decrease the resistance of the circuit? When a number of equal known resistances are connected in parallel, give a rule for finding the combined resistance.

Conclusion:

(a) Complete the following statement:

The currents in the branches of a divided circuit are ---------------- to the resistances of the branches in which they flow.

(b) Compare the sum of the reciprocals of the resistances of the branches of the circuit with the reciprocal of the resistance of the entire circuit.

EXPERIMENT 78

Resistance by Substitution

OBJECT. To determine the resistance of a coil by direct comparison with a known resistance.

APPARATUS. Galvanometer;[1] resistance box; reversing key (Fig. 97); Daniell cell, or dry cell; two resistance coils, or other resistances, about 50 to 60 ohms; copper wire for connections.

[1] If a d'Arsonval galvanometer is used, it should be protected by a shunt or by a series resistance.

Introductory:

One of the simplest methods of measuring an unknown resistance is by direct comparison with a known resistance. When the same voltage is applied, the currents in two circuits will be the same if the resistances are equal. The strength of two currents may be compared by the amounts that they deflect the needle of a galvanometer.

After reading the deflection of the galvanometer when the unknown resistance is in circuit, various known resistances may be substituted for the unknown until the same deflection of the needle is obtained as with the unknown resistance. As the only difference in the two circuits lies in the resistance (unknown or known) inserted, equal deflections mean that a known resistance has been inserted which is equal to the unknown resistance.

Experimental:

Arrange the apparatus as in Fig. 96. K_1K_2 is a reversing key (Fig. 97). The directions for the use of galvanometers on pages 13 and 14 should be read before using the instrument.

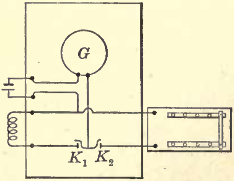

Fig. 96.

(*a*) Close the key K_1 so that the current shall pass through the unknown resistance. Gently tap the galvanometer and read the deflection. Immediately open the key.

Close the key K_2, so that the current passes through the resistance box, from which one of the plugs has been removed. Why? Remove plugs so as to obtain a total resistance which will give a deflection equal to that obtained with the unknown resistance, so far as the range of your box will permit. Keep the key depressed only when

taking readings, and tap the galvanometer, as directed above.

Again connect the galvanometer to the unknown resistance. If the reading is not the same as before, try to get a closer adjustment of the resistance box. Record the final readings of the galvanometer, connected through the known and through the unknown resistances.

Fig. 97. Reversing Key.

(*b*) Determine in a similar way the value of a second unknown resistance.

Observations

	Part A	Part B
Deflection with unknown resistance .	-----	-----
Total known resistance in ohms . . .	-----	-----
Deflections with known resistance . .	-----	-----

Make a drawing showing the arrangement of the apparatus, and describe with reference to it the experimental method. State also the precautions to be observed with regard to the galvanometer and its readings.

Discussion:

Why is the circuit kept open, except when readings are being taken? When the resistance box is in circuit, should the first resistance inserted be a large one or a small one? Explain. State why a repeated comparison is made of the readings of the galvanometer through the known and through the unknown resistance.

Conclusion:

The resistance of ______________ is ______________ ohms; that of ______________ is ______________ ohms.

EXPERIMENT 79

Heating Effect of an Electric Current

OBJECT. To measure the number of calories of heat furnished by an incandescent lamp and to calculate the cost.

APPARATUS. Calorimeter; thermometer; 16 candle power incandescent lamp; porcelain keyless socket; voltmeter; ammeter; source of 110-volt current; graduate, or balance and weights; flexible insulated wire for connections; watch or clock with second hand.

Introductory:

Electrical heating devices are widely advertised and many of them extensively used on account of their convenience. The common feature of them all is a well-insulated conductor of comparatively high resistance, made of a material capable of being heated to a high temperature without melting. The incandescent lamp has these properties and is sometimes used for heating purposes in "luminous radiators." By allowing a lamp to heat a known weight of water for a measured time, we may find the calories per second furnished by the lamp. If we know the current and voltage of the lamp, we may estimate the heat liberated per kilowatt hour. Although all the heat liberated by the lamp will not be measured in this experiment, yet the efficiency of the lamp as a heater, as used here, compares favorably with regular electrical heating apparatus.

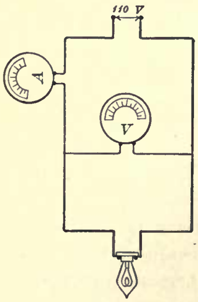

Fig. 98.

Experimental:

A porcelain keyless socket is connected to a 110-volt line, with an ammeter between the socket and the 110-volt terminals (Fig. 98). A voltmeter is connected across the terminals of the socket. A lamp is then screwed into the socket and the switch closed in the circuit to make sure that the connections are correct and that the instruments read in the proper direction. The lamp is then turned off till needed.

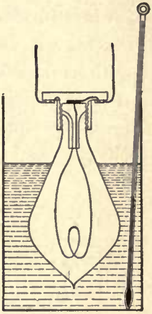

Fig. 99.

Into a nickel-plated brass calorimeter is placed 250 grams (cm.^{3}) of water at a temperature six or seven degrees below room temperature.[1] This is stirred thoroughly with a thermometer and the temperature noted; immediately the current is turned on through the lamp which is inserted in the calorimeter, the exact time in minutes and seconds being noted. The time and the temperature of the water are recorded in the tabular form near the top of the left-hand page, the voltmeter and ammeter also being read and their readings recorded. The lamp should be immersed until the tip rests on the bottom of the calorimeter, and the thermometer should stand in the calorimeter beside the lamp (Fig. 99). For the next five minutes the lamp burns inverted in the water. By moving the lamp up and down in the water, never raising it more than a quarter of an inch from the bottom, the water can be kept stirred and so of equal temperature

[1] This is the correct amount of water for the ordinary size calorimeter. The water should reach to within a quarter of an inch of the metal base of the bulb, when the latter is completely immersed. If the calorimeter is large enough to permit the use of a larger lamp, it should be used and the amount of water adjusted as just stated.

throughout. The calorimeter should not be handled during the experiment. The voltmeter and ammeter should be frequently observed, and if there is any variation, the average reading for the whole time should be the one recorded and used.

When the lamp has been in the water exactly five minutes, take it out promptly, stir the water vigorously with the thermometer, and read and record the temperature.

Using fresh quantities of water, repeat the test twice. The water equivalent of the calorimeter should be obtained from the instructor.

Observations

Trial	Time		Temperature		Volts		Amperes	
	Begin	End	Begin	End	Begin	End	Begin	End
1	-----	-----	-----	-----	-----	-----	-----	-----
2	-----	-----	-----	-----	-----	-----	-----	-----
3	-----	-----	-----	-----	-----	-----	-----	-----

Weight of water . . . . *g.*
Water equivalent of calorimeter . . . . . *g.*

Make a sectional drawing of the calorimeter with lamp and thermometer in place and with the connections of the instrument shown. A brief description of the method of the experiment should accompany the drawing.

From the weight of the water, with the water equivalent of the calorimeter added, and the change of temperature, the number of calories furnished in five minutes can be calculated. The number of watt-seconds is found by multiplying volts, amperes, and seconds together. From these two results calculate the calories per watt-second

and per kilowatt hour. As the time and the weight of water are the same in all three tests, the averages of temperature changes, volts, and amperes will be used in the calculation. The problem called for in the conclusion should be worked out in the note-book, using the local rate for electricity.

Calculated Results

Corrected weight of water (water + water equivalent of calorimeter)	*g.*
Average temperature change in five minutes .	*°C.*
Calories furnished in five minutes	*cal.*
Calories furnished per second	*cal.*
Watt-seconds of energy used in five minutes .	*w.s.*
Calories per watt-second	
Calories per kilowatt hour	
Cost of current per kilowatt hour	*cts.*

Discussion:

Explain any way in which heat generated by the lamp may escape without being measured in this experiment.

Conclusion:

At the price of ..... cents per kilowatt hour, the cost of raising 4 liters of water from 15° C. to 100° C. will be ..... cents, if an electric heater of the same efficiency as the lamp is employed.

EXPERIMENT 80

Study of an Incandescent Lamp

OBJECT. To measure the current, voltage, resistance, and power consumption of an incandescent lamp.

APPARATUS. Lamp socket, mounted on block with two binding posts connected to the socket; 16 and 32 candle power incandescent lamps; low-range ammeter; 120-volt voltmeter; one or more lamps with the metal cap removed; at least one tungsten lamp, of known candle power; # 18 wire for connections to source of 110-volt current.

Introductory:

When we pay for electric light, we desire to get as much as possible for our money. We need to know the pressure required and the current consumed by our lamps. From these we can calculate the resistance of the lamp and the power in watts required to light it. By the use of a voltmeter and an ammeter properly connected to the lamp, we can observe the pressure and current directly. The resistance may be calculated by applying Ohm's Law. The watts are equal to the volts multiplied by the amperes.

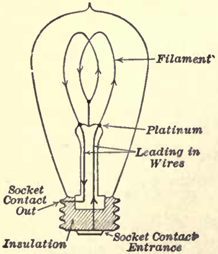

Fig. 100.

Experimental:

Connect the ammeter in series with the lamp and the source of current. Connect the voltmeter to the terminals of the lamp socket, so that it will measure the fall of potential through the lamp only. Readings are to be made with 16 and 32 candle power lamps, and the results worked

out in each case. Readings with a tungsten lamp should be made by some members of the class. The results may be entered by the other members of the class for purposes of comparison. Assuming the candle power to be correctly stated for the lamp, the number of watts required for each unit of candle power of the lamp should be calculated. This is known as the efficiency of the lamp, and, since power is what we pay for, it is used in comparing the economy of different kinds of lamps.

The readings obtained should be recorded in tabular form near the top of the left-hand page.

Observations

	Current	Voltage
16 candle power lamp	*amp.*	*volts*
32 candle power lamp	*amp.*	*volts*
__ candle power tungsten lamp .	*amp.*	*volts*

A careful outline drawing, showing a vertical section of the lamp, with the parts labeled, should be made, in addition to the diagram showing the connections.

At the top of the right-hand page place the results obtained by calculation.

Calculated Results

	Resistance	Power	Efficiency
16 candle power lamp .	*ohms*	*watts*	$\frac{watts}{c.p.}$
32 candle power lamp .	*ohms*	*watts*	$\frac{watts}{c.p.}$

Conclusion:

The average efficiency of a carbon incandescent lamp is ----- $\frac{\text{watts}}{\text{candle}}$; of a tungsten lamp is ----- $\frac{\text{watts}}{\text{candle}}$.

EXPERIMENT 81

Lines of Force around a Conductor

OBJECT. To investigate the magnetic field surrounding a conductor.

APPARATUS. No. 10 copper wire, bent at right angles and provided with binding posts or double connectors at the ends; dry cell or other source of current; reversing switch; # 18 insulated copper wire for connections; 4 small exploring compasses; 2.5 cm. compass; support which will permit the exploring compasses to be placed around the vertical portion of the wire, while the larger compass may be placed either above or beneath the horizontal portion.

Introductory:

When a current passes through a wire, magnetic effects may be observed in the vicinity of the wire. As such effects are always associated with the presence of lines of force, we wish to explore the field around the conductor to find the direction of these lines. This may easily be done by using compass needles, if we remember that a magnetic compass will set itself tangent to a line of force, and that a north pole will point in the direction of a line of force.

Experimental:

The direction of the current is from the + terminal of the cell, or dynamo, to the apparatus. Trace the current through the apparatus and back to the − terminal.

[1] *Note to Instructor.* The apparatus may be assembled permanently in the form shown in Fig. 101. The small compasses are set in holes bored in the block with a bit and cemented in place by rubbing them with a little shellac just before they are set in place.

(*a*) We may determine the direction of the magnetic field around a conductor passing vertically through a block by placing small compasses on the block around the wire and observing their position, —

(1) when there is no current flowing;
(2) when the current flows up;
(3) when the current flows down.

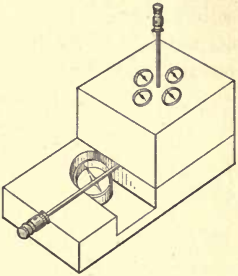

Fig. 101.

The observations are to be recorded in three diagrams at the top of the left-hand page. In each diagram the position taken by the small needles is to be shown by arrows in the four larger circles. The small circle in the center represents the wire. A current flowing up (toward the observer) is represented by a dot in a circle, thus ⊙; a current flowing down (away from the observer) by ⊗. These signs represent respectively the point of an arrow coming toward the observer and the feathers of an arrow going away from him. A sample diagram, showing the position of the needles in one case, is given in Fig. 102.

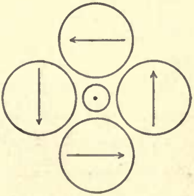

Fig. 102.

(*b*) Place your apparatus so that the horizontal wire is parallel to one needle when no current is flowing. Place the compass under the wire and turn on the current. Observe the direction of deflection of the needle and record in diagrams, similar to that shown in Fig. 103, placed in the upper part of the *right-hand* page. Note beside each diagram the posi-

tion of the wire with respect to the needle (*wire above* or *wire below*). The dotted arrow indicates the original position of the needle before the current passes and the solid arrow the position of the needle during the passage of the current. In all representations of the compass needle, the arrowhead indicates the north pole.

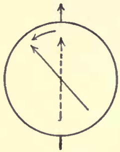

Fig. 103.

Observe and record in the manner just described the four following cases:

(1) Current S to N, wire over needle;
(2) Current N to S, wire over needle;
(3) Current S to N, wire under needle;
(4) Current N to S, wire under needle.

A simple outline drawing of the apparatus should be made on the left-hand page immediately below the diagrams of results, and a brief description of operations written, referring to the drawings and diagrams. On the lower part of the right-hand page state the conclusions.

Conclusion:

(1) What is the shape of the lines of force around a straight conductor?

(2) Imagine the current as flowing in your right hand toward the fingers. If the palm faces the needle, toward what part of the hand is the needle deflected? Make a full statement of this relation.

(3) Suppose the wire to be grasped in the right hand, with the current flowing in the direction in which the thumb points. In what direction do the lines of force extend? Make a full statement of this relation.

EXPERIMENT 82

The Electromagnet

OBJECT. To study the construction of the electromagnet, and to determine the conditions of its operation.

APPARATUS.[1] Three electromagnet coils;[2] a good dry cell; single contact key; small box of half-inch brads; # 18 wire for connections; compass.

Introductory:

Doorbells, telegraph instruments, dynamos, motors, and many other kinds of electrical apparatus depend for their operation on electromagnets. These electromagnets consist of coils of wire, or solenoids, usually containing an iron core. We wish to locate the poles of such a magnet, to find the effect of the iron core on the strength of the magnet, and to find the effect of the number of turns of wire. Later experiments will take up applications of the electromagnet.

Experimental:

(*a*) Connect the terminals of the coil wound on the wooden core (Fig. 104, *C*) to the dry cell through the contact key. By means of a compass needle, determine which

[1] The authors are indebted to Mr. W. R. Pyle, Morris High School, N. Y. City, for the plan of this experiment.

[2] Two of the coils are wound on ¼″ soft iron cores and the third on ¼″ dowel rod. The ends of the iron cores should be rounded off, as shown in Fig. 104, to increase the effect. On one of the iron cores (*B*) wind 100 turns of # 22 insulated wire; the ends of the coil are held in place by rubber rings, cut from a piece of tubing, with a slightly smaller internal diameter than the rod. After winding, the magnet is dipped in shellac, to hold the windings and rings in place. On the wooden core an exactly similar winding is placed and shellacked. The other iron core (*A*) is similarly wound, but with 50 turns only.

end of the coil acts like a north pole and which end like a south pole. The key should be closed only when readings are being made, as otherwise the cell will rapidly polarize. Trace the direction of the current from the positive (carbon) pole of the cell through the coil, noting particularly the direction in which it flowed around the coil. Record this in the form of a simple diagram, showing only a very few turns of wire wound on the core, with an arrowhead on each to show the direction of the current, and with the poles marked.

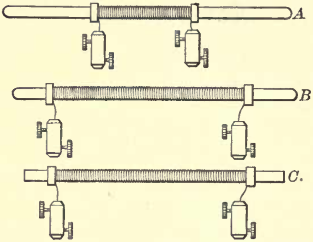

Fig. 104.

Grasp the coil in the right hand, with the fingers pointing around it in the direction of the current and the thumb extended. Does the thumb point in the direction of the north pole or in the direction of the south pole of the coil? *State the relation in full in the Discussion.*

(*b*) Using the coil (Fig. 104, *A*) having the smaller number of turns wound on an iron core, test for polarity as in (*a*). *Does the presence of an iron core change the relation between the direction of the current around the magnet and the location of the poles?*

Test the strength of the electromagnet by pushing one end into a box of brads, and then closing the circuit and removing the magnet with the brads which stick to it. Observe the behavior of the brads when the circuit is opened. What does this behavior indicate? The brads picked up by the electromagnet should be counted and the number recorded.

(*c*) Determine the number of brads which can be picked up by the coil with the larger number of turns and the iron core (Fig. 104, *B*), and record. Count the number of turns on each of the three coils. *How is the strength of an electromagnet affected by the number of turns of wire it has?*

(*d*) Try to pick up brads with the coil on the wooden core, and record the result. *What effect has the use of an iron core on the strength of an electromagnet?*

Record the numerical results obtained in tabular form near the top of the left-hand page.

OBSERVATIONS

MATERIAL OF CORE	NUMBER OF TURNS	NUMBER OF BRADS PICKED UP
-----	-----	-----
-----	-----	-----
-----	-----	-----

A brief description of the tests made should follow the table of observations and should include such observed results as are not stated in the table. A simple drawing should be made, showing one of the coils connected with the cell and key.

Discussion:

The questions in italics in the experimental directions should be answered under this heading.

Conclusion:

State the conditions necessary for a strong electromagnet.

EXPERIMENT 83

The Electric Bell

OBJECT. To study the construction and operation of the electric bell.

APPARATUS. Electric bell with cover removed; dry cell; push button; #18 wire for connections; magnetic compass. It is desirable to bend the hammer rod so that the hammer does not actually strike the bell.

Introductory:

The electric bell is one of the most familiar applications of the electromagnet. A clear understanding of its construction, therefore, is of value to enable us to know what may be expected of the bell and what adjustments are necessary when it fails to operate properly.

Experimental:

(*a*) Connect the bell, the cell, and the push button in series, so that the bell will ring when the circuit is closed by the push button.

(*b*) Trace the path of the current through the bell, starting at one of the binding posts. What draws the hammer toward the bell? What draws the hammer away from the bell?

(*c*) Place a compass needle near the ends of the magnet coils. Hold the armature against the contact screw. Close the circuit and observe the result. Repeat with the armature held against the magnet poles. Is the magnet stronger when the armature is pressed against the contact, or when it is against the poles?

(*d*) Detach the wire from the binding post on the

armature side of the bell, and press the end of the wire against the contact screw. Close the circuit. Note and explain the difference in operation.

(*e*) On the right-hand page, make a full-size diagram of the instrument and its connections. Indicate by arrows the direction of the current at each important point.

Label the following parts:

electromagnet cores
contact screw
spring
electromagnet yoke
vibrating armature
push button.

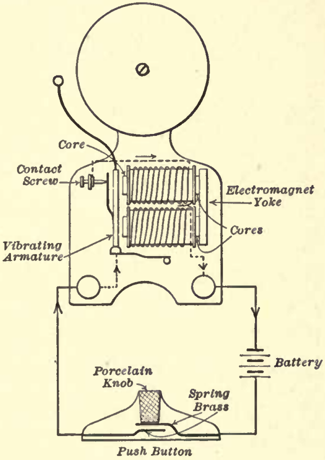

Fig. 105.

(*f*) Examine a push button and determine how the contact is made. Below the diagram of the bell, make a sketch of a vertical section of the push button and show the proper connections of battery, push button, and bell.

Discussion:

Explain the results of the tests in part (*c*). Why is the operation continuous when the circuit is closed?

What change in connections would convert this into a single-stroke bell, in which the gong is struck but once each time the circuit is closed?

Make diagrams showing the connections necessary for

(1) two bells rung by one push button; (2) two push buttons used to ring the same bell. Show the cell in each case.

EXPERIMENT 84

Telegraph Instruments

OBJECT. To study the construction and operation of the instruments used on a telegraph line.

APPARATUS. Telegraph key and sounder; dry cell or other source of current; # 18 wire for connections; at least one relay, properly connected in circuit with a key and sounder, for the laboratory, — if possible one for each laboratory table; compass.

Introductory:

Joseph Henry, who made the first electromagnets in this country, suggested the possibility of sending signals to a distant point, and fifteen years later Morse constructed the first practical telegraph line. The telegraph is, therefore, the earliest application of the electromagnet and one of the simplest and most useful electrical devices that we have.

Experimental:

(1) A telegraph key and a sounder, a cell, and connecting wires will be furnished you. These are to be connected in such a way that a current will pass through the sounder from the cell when the key is depressed. After satisfying yourself that the connection is properly made, the circuit should not be closed unnecessarily, as the noise is distracting to others.

(2) Press the key; observe and record the resulting movement in the sounder. If the instructor so directs,

produce a dot, a dash, and any combination he may require, *under his observation.*

(3) Trace the path of the current through the entire circuit. Holding the compass near the top of one of the electromagnet coils, determine whether the magnet is stronger when the key is open or when it is closed. *Account for the effect produced by closing the key. Account for the effect when the key is opened.* Operate the short-circuit lever at the side of the key.

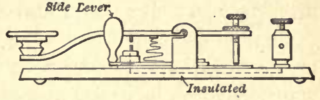

Fig. 106. The Key.

(4) On the upper half of the *right-hand* page, make drawings of the key and of the sounder, seen from the side. Make a simple diagram showing the arrangement of battery, key, sounder, and connecting wires. Connections in the instruments themselves, which are not externally visible, may be indicated by dotted lines. Mark the following parts: In the sounder — magnet coils, soft iron armature, locker arm, pivot, spring. In the key — lever, pivot, contact points, spring. Indicate the position of any insulating material. Show by dotted lines the path of the current through base, pivot, and lever.

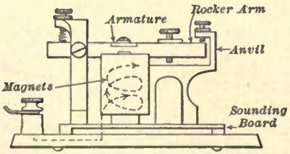

Fig. 107. The Sounder.

(5) Examine the construction of a relay, if one is available. Trace the connections in its circuits and state what connections are made from the outside to each pair of binding posts.

The drawings called for in (4) should be made first; any additional description of the instruments should be placed on the left-hand page, accompanying a statement of

facts observed in the examination and tests of the instruments.

Discussion:

Answer the italicized questions in the experimental directions as well as the following:

Explain the use of the side lever in a line including two or more stations whose instruments are in series. How many keys can be in use in such a line at a time? Why? Why can a relay be operated by a weaker current than a sounder needs? Explain the use of a relay in a telegraph circuit.

EXPERIMENT 85

Operation of an Electric Motor

OBJECT. **(*a*) To observe the effect of a magnetic field on a current-bearing conductor; (*b*) to study the construction and operation of an electric motor.**

APPARATUS. Rectangular loop of #28 spring brass wire, about 10 inches long and $1\frac{1}{2}$ inches broad (Fig. 108); large U-shaped magnet, like those used in making magnetos or voltmeters; 2 storage or dry cells; reversing switch; 4 or 6 volt motor, with drum-wound armature, mounted so that the connection of the field leads to the armature can be reversed; #18 insulated copper wire for connections.

Introductory:

The electric motor consists essentially of a coil of wire (armature) carrying a current, which rotates between the poles of an electromagnet. A commutator on the armature shaft keeps the current flowing in a constant direction through the armature. The wires on the opposite

sides of the armature are caused to move by their lines of force seeking to become parallel with the lines of force of the field. By passing a current, first in one direction and then in the other, through a pliable wire located in a magnetic field, we can imitate the action of the two wires forming the opposite sides of a coil on the armature.

Experimental:

(*a*) Pass a current through the loop of wire from a storage cell or dry cell. The circuit should be closed only when making tests. Bring the horseshoe magnet into such a position that the loop will be opposite the opening between the poles. Have the north pole of the magnet at the top, so that the magnetic field will be downward. Observe the behavior of the wire.

Make a diagram, showing by a few lines of force in each case the field due to the magnet and that due to the current in the loop of wire. Indicate on the diagram, by arrows properly placed, the direction of the current, of the lines of force, and of the motion of the loop. Repeat the test, with the direction of the current in the loop reversed. Record the result in another diagram.

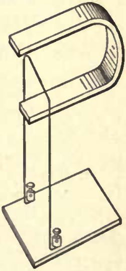

Fig. 108.

(*b*) Connect the field terminals and the armature terminals of the motor furnished, thus making it a shunt motor. Next connect the armature terminals through a reversing switch to two or more cells in series. Close the switch, and observe the direction of rotation of the armature. Reverse the switch and again observe the direction of rotation. Keeping the direction of the current in the armature the same, change the direction of current through the field, by reversing the connection of

the field terminals. Observe the direction of rotation in this case.

The results of the tests in part (*a*) are to be recorded in the two diagrams, which should be accompanied by a brief description of the operations. The results in part (*b*) should be stated in connection with the description of the work. This description should be accompanied by a drawing showing a side view of the motor, in which the following parts are shown and labeled:

field magnet armature brushes commutator

Discussion:

Does this experiment illustrate the following rule for the motor? "Let the forefinger of the *left* hand point in the direction of the magnetic field, and the second finger at right angles to the forefinger, in the direction of the current; then the thumb will indicate the direction in which the current-bearing conductor will move."

To reverse a motor, should both field and armature connections be reversed, or only one of them?

EXPERIMENT 86

Power and Efficiency of a Motor

OBJECT. To determine the horse power developed by an electric motor and the efficiency of the motor when developing that horse power.

APPARATUS. Electric motor, not smaller than $\frac{1}{4}$ H.P., with starting box and proper connections to a source of current; canvas or leather strap, equal in width to the pulley of the motor, with two spring balances of 12 lb. capacity; suspension bar for the balances and strap, with an upright support to which it can be clamped (Fig. 110); speed counter; watch; voltmeter and ammeter.

Introductory:

In the selection of a motor, whether it is to run an automobile or a sewing machine, the first consideration is to secure one that has the proper horse power. When a motor of the proper power has been found, then the efficiency with which it does its work should be investigated. Both the power and the efficiency of a motor can be measured with very simple apparatus.

To calculate the horse power, it is necessary to find the number of foot pounds of work done per minute and divide this by 33,000, according to the definition of horse power. The number of foot pounds can be found by measuring with a spring balance the number of pounds friction between the motor pulley and a brake against which it turns, and multiplying this result by the total number of feet which a point on the revolving pulley will travel in one minute. The rated horse power of a motor or engine is the power it develops when working at full load; it does not develop this power at all times.

The efficiency of a machine is the percentage of total work done on the machine which proves useful, or, since power is the rate of doing work, it is the percentage of total power applied to the machine which proves useful. By measuring the amperes of current flowing through the motor and the voltage applied to the machine, we can calculate the power applied in watts. Since 1 horse power is equal to 746 watts, the ratio of the power exerted by the motor on the brake and the power applied to the motor by the current is readily found.

Experimental:

The motor, voltmeter, and ammeter should be connected to a source of current, as shown in Fig. 109, according to specific directions to be given by the instructor. Unless

a starting box is provided, the ammeter terminals should be short-circuited by a switch, which should not be opened until the motor has reached full speed. If a starting box is used, the ammeter should be connected between the source of current and the starting box, so that its readings shall show the current taken by both armature and field. The voltmeter, in any case, should be directly across the armature terminals of the motor.

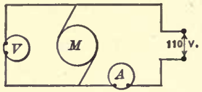

Fig. 109.

The brake consists of a strap, hung by two spring balances from an adjustable support. By raising this support until the bend in the strap is held against the under side of the motor pulley by the partly stretched springs of the balances, a frictional force is exerted on the surface of the pulley, the amount of which is equal to the difference between the readings of the two balances.

The diameter of the pulley and the thickness of the belt in inches should be measured before the test is started and recorded in the tabular form near the top of the left-hand page. A speed counter and watch should be at hand, ready for use, and the student who is to take the speed should be given specific directions by the instructor. When everything is ready, one student should take charge of the management of the brake and reading of the balances, a second should take the number of revolutions made in one minute, a third should watch the ammeter dur-

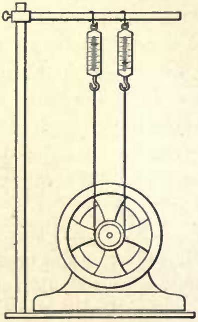
Fig. 110.

ing the minute and record its average reading, and a fourth should do the same for the voltmeter.

(*a*) After the connections have been approved by the instructor, start the motor. Make sure that it is running in the right direction and that the voltmeter and ammeter are connected so that their needles read in the right direction. Adjust the tension of the brake by raising the supporting arm, so that the ammeter indicates about half as much current as the normal load of the motor requires. The voltmeter, ammeter, and spring balances should then be watched for one minute, while the speed is being taken, and all readings recorded. A second set of readings should be taken under the same conditions. If there is any marked variation in either voltmeter or ammeter readings during either minute, the results for that minute should be discarded and another reading taken.

(*b*) Increase the tension of the brake, so that the motor takes the full number of amperes for which it is designed. Make two sets of readings, like those in (*a*), and record.

Observations

Diameter of pulley ----- in. Thickness of strap ----- in.

Trial	Balance Readings		Speed	Pressure	Current
	High	Low			
a–1	------ lb.	----- lb.	----- R. P. M.	----- v.	----- amp.
a–2	------ lb.	----- lb.	----- R. P. M.	----- v.	----- amp.
b–1	----- lb.	----- lb.	------ R. P. M.	----- v.	------ amp.
b–2	----- lb.	----- lb.	----- R. P. M.	----- v.	------ amp.

Make a diagram of the electrical connections and an outline drawing showing the brake in place on the pulley; write a brief description of the method.

Calculation of Horse Power. — The force exerted by the pulley on the brake is evidently the difference between the two balance readings, as when the pulley is turning there is more pull on one of the balances and less on the other than when the pulley is at rest, with the support of the brake in the same position. As a large portion of the pulley is always in contact with the brake, the distance through which the frictional force between the brake and the pulley acts in a minute is the same as the distance traveled by a point on the circumference of the pulley in a minute. In calculating this circumference, half the thickness of the belt is added to the radius of the pulley, and this measurement is reduced to *feet*. So the work per minute equals (difference between balance readings) $\times$ (diameter of pulley + thickness of belt) $\times \pi \times$ (revolutions per minute). Dividing the foot pounds per minute by 33,000 gives the horse power.

Calculation of Efficiency. — The horse power obtained multiplied by 746 gives the power output in watts. The product of the volts and amperes gives the power input in watts. The former divided by the latter is the efficiency.

The horse power and the efficiency at half load and at full load should be calculated, taking the average of the two readings in (*a*) for one calculation and the average of the readings in (*b*) for the other.

Calculated Results

Trial	Net Force	Distance per Min.	Foot Pounds per Min.	Horse Power	Watts Output	Watts Input	Efficiency
a	----- lb.	----- ft.	----- ft. lb.	----- H.P.	-----	-----	----- %
b	----- lb.	----- ft.	----- ft. lb.	----- H.P.	-----	-----	----- %

Discussion:

Is the electrical energy consumed by a given motor independent of the work the motor is doing or dependent upon it? Does the motor always work at full horse power? Is it better economy to select small motors for a factory and run them at full load, or large ones and run them at half load? Would any energy be required to run a motor with no external load? What would be the efficiency of a motor at no load? Is the change in speed of your motor comparable in amount to the change in load?

Conclusion:

The maximum horse power obtained from the motor tested was ----- H.P.

The efficiency at maximum horse power was ----- %. The efficiency of a motor is ----- at full load than at partial load.

EXPERIMENT 87

Relation between Fall of Potential and Resistance

OBJECT. **To determine the relation between the fall of potential in different parts of a circuit and the resistance of those parts of the circuit.**

APPARATUS. High resistance wire, # 22 Prima Prima (Ia Ia),[1] mounted on a meter stick; voltmeter, low reading; ammeter, low reading; sliding contact; dry or storage cells to give about 6 volts; wire for connections.

Introductory:

When a power house is delivering current to some distant point, it is found that the voltage is higher at the power house than at the other end of the line. There has occurred a drop in voltage, which is equal to the pressure necessary to send the current through the line. By comparing the drop in voltage between the generator and different points with the resistance of the line between the generator and those points, the relation between the drop in any part of the circuit and the resistance of that part of the circuit may be determined.

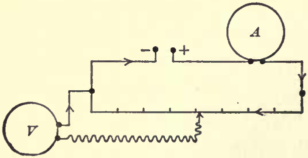

Fig. 111.

[1] This may be obtained from Hermann Boker and Company, 101 Duane St., New York. German silver wire may be used instead, but its resistance is not so high as the Ia Ia, and the latter has a negligible temperature coefficient.

Experimental:

Connect a high resistance wire 1 meter long in series with an ammeter and storage cells. To the zero end of the wire connect the proper terminal of a low-reading voltmeter. Connect the other terminal of the voltmeter with a sliding contact. Examine all connections to see that the polarity is correct.

Close the switch and place the sliding contact at the end of the wire opposite to the other voltmeter connection. Read the current, the length of the wire, and the potential difference between the ends. Move the sliding contact 10 cm. toward the fixed contact and read as before. Repeat, moving 10 cm. at a time until the fixed and movable contacts touch.

Record all readings in tabular form near the top of the left-hand page.

OBSERVATIONS

	1	2	3	4	5	6	7	8	9	10	11
Length of resistance wire in cm.	100	90	80	70	60	50	40	30	20	10	0
Potential difference between ends	..	..	..	..	..	..	..	..	..	..	..
Current strength	..	..	..	..	..	..	..	..	..	..	..

Make a diagram showing the connections, and, referring to the diagram, write a brief description of the method.

From the laws of resistance, we may assume that the resistance of different lengths of the wire are proportional to the lengths. By subtracting each reading of length from 100 cm., the change in length of the wire is found. By subtracting each voltmeter reading from the reading for the whole wire, the fall of potential for each change of length is found. These subtractions should

be made in order, beginning with the first two readings, and the results recorded in the table at the top of the right-hand page. In case the current changes during the experiment, calculate the resistance of each 10 cm. length, and record the changes in resistance instead of the changes in length.

CALCULATED RESULTS

	1	2	3	4	5	6	7	8	9	10
Change in length of wire	..	..	..	..	..	..	..	..	..	..
Fall of potential	..	..	..	..	..	..	..	..	..	..

Discussion:

What do the readings of the ammeter measure? Those of the voltmeter? How could the actual resistance of any part of the wire be calculated? If the current remains constant, to what do you attribute the differences in the fall of potential in different lengths of the wire?

Conclusion:

What is the relation between the fall of potential in different parts of a circuit and resistances of those parts of the circuit?

EXPERIMENT 88

Resistance by the Wheatstone Bridge

OBJECT. To measure the resistance of a conductor by means of the Wheatstone bridge.

APPARATUS. Wheatstone bridge, slide-wire form; galvanometer; contact key; plug resistance box; Daniell cell, or dry cell; wire for connections; three coils or other pieces of apparatus for resistance measurement (resistance about 6 to 15 ohms).

Introductory:

The Wheatstone bridge provides a rapid, accurate method of measuring a wide range of resistance (1,000,000 or more ohms to a thousandth of an ohm with some forms of bridge). The theory of the bridge is based on Ohm's Law of the fall of potential in a circuit. The method of its use depends upon comparing the ratio between a known and an unknown resistance, with the ratio between two known resistances. The four resistances are connected as shown in Fig. 112, AB containing the unknown resistance, R_1, BC a resistance box, R_4, and AD and DC resistances, R_2 and R_3, whose ratio is known.

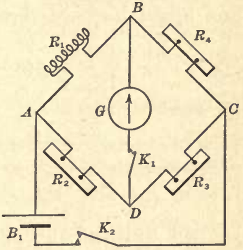

Fig. 112.

When B and D have the same potential and are connected through the galvanometer, no current will flow. Hence the needle is not deflected and the bridge is said to be balanced. The ratio $\frac{R_1(\text{unknown})}{R_4(\text{known})}$ is the same as the ratio $\frac{R_2}{R_3}$, a known ratio. In the slide-wire bridge (Fig. 113), ACB is a uniform wire, so $\frac{X}{R} = \frac{R_{\text{I}}}{R_{\text{II}}} = \frac{\text{length } AC}{\text{length } CB}$. Thus, when the bridge is balanced, the lengths AB and CB are measured, the resistance R is known, and it is an easy matter to calculate the unknown resistance.

Experimental:

Arrange the apparatus as in Fig. 113, inserting a single contact key between one side of the cell and the

bridge. Notice that the current flows in a divided circuit through the bridge. Trace the current in each branch.

Make the resistance in the resistance box 5 ohms for the first test. Close the key in the battery circuit, and then touch the wire at the 50 cm. point with the movable galvanometer contact. Observe the direction and the amount of deflection of the galvanometer. It is not necessary to record these. Increase the resistance in the box by 1 ohm, and again test. Judge by the direction and amount of deflection whether the resistance in the box is too much or too little. Change the resistance in the box until the deflection is small, and then shift the movable contact until no current flows through the galvanometer. Record the resistance in the box and the distance of the sliding contact, as measured from each end of the metric scale, in a tabular form near the top of the left-hand page. Also specify the material and length or number of the coil whose resistance is being measured.

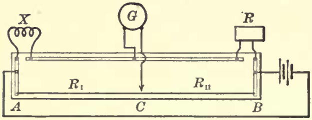

Fig. 113.

Make a similar set of measurements for two other coils of unknown resistance.

Observations

Description of Coil Measured	Resistance in Box R	Length AC	Length CB
-----	----- *ohms*	----- *cm.*	----- *cm.*
-----	----- *ohms*	----- *cm.*	----- *cm.*
-----	----- *ohms*	----- *cm.*	----- *cm.*

Make a drawing showing the arrangement of the apparatus. Describe the method of balancing the bridge.

Let X represent the unknown resistance. When the resistance (R) has been found for which no current flows through the galvanometer, the proportion $\frac{X}{R}=\frac{AC}{CB}$ is true. Hence $X=\frac{R \times AC}{CB}$.

Calculate the value of each of the three unknown resistances. Record in tabular form at the top of the right-hand page.

Calculated Results

Description of Coil X	Calculated Resistance
----------------	---------------- *ohms*
----------------	---------------- *ohms*
----------------	---------------- *ohms*

Discussion:

Explain the relation $\frac{X}{R}=\frac{AC}{CB}$ by the principle developed in the fall of potential experiment (Experiment 87, p. 296). Under what conditions only will no current flow through the galvanometer circuit? Show that this condition can be proved by Ohm's Law, since $E=IR$.

EXPERIMENT 89

Induced Currents

OBJECT. To cause induced currents to flow through a coil of wire and to determine the laws of such currents.

APPARATUS. Coil of 100 or more turns of fine insulated wire, so wound that the direction of winding may be clearly seen; sensitive galvanometer; strong horseshoe magnet, such as is used in telephone magnetos, mounted in an upright position.

Introductory:

The dynamo, the induction coil, and the transformer illustrate the production of electric currents through closed circuits of wire which do not contain any voltaic cells. In each of these cases, an electromotive force is produced by moving coils of wire in such a way that they cut magnetic lines of force, or moving the lines of force so that they cut the coil. This process of producing an electromotive force is called *electromagnetic induction.*

Experimental:

Connect a coil of fine wire with a sensitive galvanometer. The terminal of the galvanometer at which the current enters to produce a deflection in a given direction must be known. Support a horseshoe magnet in an upright position and move the coil rapidly downward over the north pole of the magnet. By means of a diagram like Fig. 114, record, near the top of the right-hand page, the direction of motion of the coil, the direction of winding of the coil, and the terminal of the galvanometer at which the current enters. This terminal should be marked +. After making this diagram, indicate by arrowheads the

direction which the current takes through the coil. The deflection of the galvanometer is to be recorded beside the diagram as "large" or "small." Observe whether the induced current continues after the motion of the coil has stopped.

Allow the galvanometer to come to rest, then rapidly draw off the coil, observing and recording as before, by means of another diagram. Repeat the test with the south pole. Record in a third and in a fourth diagram. Repeat any one of the tests, moving the coil more slowly. Record in a fifth diagram. Is the direction of deflection the same as when the coil was moved more rapidly? Is the magnitude of deflection the same?

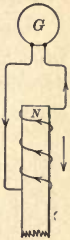

Fig. 114.

Place the coil over one pole of the magnet, and vary the magnetic field by suddenly pulling off the armature. This causes an increase in the lines of force in the field surrounding the magnet. Record this result as before in a diagram. Next suddenly replace the armature, thus lessening the number of lines in the space around the magnet, and record this result.

The seven diagrams take the place of a table of observations. It is very important that each diagram be a complete record of the test recorded by it; so be sure that the sign of the pole, the direction of motion of the coil, the direction of current in the coil, and the relative amount of current are indicated.

No additional drawing is necessary, but the tests made should be briefly described.

Discussion:

How long is an induced electromotive force maintained? What would be the probable effect of using a coil of a less

number of turns? When the coil is moving toward the pole of the magnet, does the pole of the coil attract or repel that of the magnet?

When the coil is moving off the magnetic pole, is there attraction or repulsion between its pole and that of the magnet?

Conclusion:

How may an electromotive force be induced? Upon what does the direction of an induced electromotive force depend? Upon what does the amount of the induced electromotive force depend?

EXPERIMENT 90

Study of a Dynamo

OBJECT. **To observe the generation of current in a simple dynamo and to study the construction of a direct current dynamo.**

APPARATUS. Large U-shaped magnet, mounted with its poles vertical; coil of fine wire wound on a wooden or an iron core, to be revolved between the magnet poles; sensitive galvanometer; two-pole, drum-wound small dynamo (6–8 volts); voltmeter; dry or storage cell, or other source of current for exciting the field of the dynamo.

Introductory:

Voltaic cells are not adapted to produce high pressures and large currents. Hence dynamos are employed in commercial work. Their action depends upon the fact that when a conductor cuts across magnetic lines of force, a difference of potential is produced in the conductor. The electromagnet which produced the lines of force in a

dynamo is called the *field magnet*. The conductors which cut the lines are wires wound about a soft iron core. The wires and core together constitute the *armature*. The current generated in the armature is led out into the external circuit by means of *brushes*, which make a sliding contact with bars connected to the ends of the armature coils. These bars may be so placed and connected that the brushes change their contact from one bar to the next at just the instant when the difference of potential changes direction. The bars then constitute the *commutator*. We shall first observe the generation of voltage in a simple dynamo and then examine a machine of commercial type to locate the parts just described.

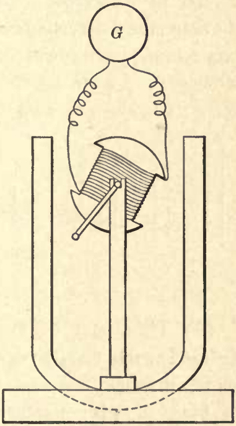

Fig. 115.

Experimental:

(*a*) Connect the long, flexible leads of the armature coil furnished you with the galvanometer (Fig. 115). Hold the armature between the poles of the coil in a vertical position. Turn the coil sharply through a quarter of a revolution and observe the behavior of the galvanometer. If you do not know from the direction of deflection of the galvanometer the direction of current flow in the two connecting wires, ask the instructor to show you how to determine this. In a diagram like that shown in Fig. 116, *A*, placed near the top of the left-hand page, record the direction of rotation, the direction of the magnetic field, and the direction of flow of current in the wires on each side of the armature.

The other three tests to be made are to be recorded in similar diagrams, placed beside this one (Fig. 116; *B*, *C*, *D*).

Turn the coil through the next quarter turn, observe the direction of deflection of the galvanometer, and record the results in a diagram like that for the first quarter turn. Repeat the process and make similar records for the third and fourth quarters of the revolution. The current induced in this simple dynamo is an alternating current. *In how many directions does the induced current flow during one complete revolution of the armature?*

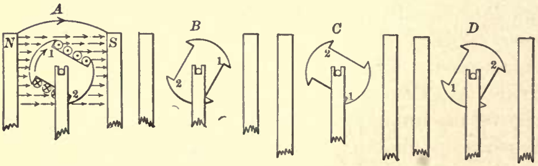

Fig. 116.

(*b*) This part of the experiment should not be performed with the three-pole armature type of toy motor or generator.

The following parts of the dynamo should be located, and a sketch of the machine made showing them: field magnet, armature, brushes, commutator. Report on the following points of construction in your note-book:

(1) Where and how the connection of one coil to another is made.

(2) The connections made to each commutator segment.

Connect the armature terminals to a voltmeter or to the galvanometer used in part (*a*). Supply current to the field from a dry or other cell. By twisting the armature with your thumb and finger, verify the statement that voltage is produced when lines of force are cut. Turn the

armature in the opposite direction and note the effect. *Would the dynamo generate if the field magnet were connected to the brushes, instead of to some external source of current?*

The description should include the results of any observations not recorded in the diagrams called for above.

Discussion:

Answer the italicized questions occurring in the experimental directions.

Show that the coils are so connected that the sum of the electromotive forces generated in them shall be the electromotive force at the brushes.

Conclusion:

State the use of each part of the dynamo, — magnet, armature, commutator, brushes.

APPENDIX

I. Important Numbers and Equivalents

$\pi = 3.1416$

$\pi^2 = 9.8696$

Circumference of a circle $= \pi D$

Area of a circle $= \pi r^2$ or $\frac{\pi D^2}{4}$

1 centimeter = 0.3937 in.

1 inch = 2.54 cm.

1 mile = 1.609 kilometers

1 cubic inch = 16.387 $cm.^3$

1 pound avoir. = 453.6 g.

1 ounce avoir. = 28.35 g.

1 kilogram = 2.2 lb.

1 liter = 1.0567 qt. (liquid)

1 $cm.^3$ water at 4° C. = 1 g.

1 $ft.^3$ water at 4° C. = 62.4 lb.

1 atmosphere = 14.7 lb.

1 atmosphere = 76 cm. mercury

1 atmosphere = 30 in. mercury

1 atmosphere = 33.57 ft. water

Energy consumed in heating 1 lb. of water 1° F. (1 B. T. U.) = 778 ft. lb.

Energy consumed in heating 1 g. of water 1° C. (1 calorie) = 3.09 ft. lb.

1 British Thermal Unit (B. T. U.) = 252 calories

1 horse power = 550 ft. lb. per second = 33,000 ft. lb. per minute = 746 watts = $\frac{3}{4}$ kilowatt, nearly

1 kilowatt = 1000 volt-amperes = $\frac{1000}{746}$ horse power = $\frac{4}{3}$ horse power, nearly

Heat in calories developed by resistance = 0.24 × amperes^2 × ohms × seconds = 0.24 watt-seconds

II. Properties of Materials

Substance	Specific Gravity Water = 1	Melting Point ° C.	Boiling Point ° C.	Specific Heat	Coefficient of Expansion	
					Linear	Cubical
Aluminum	2.6	657	1500–1700	0.22	0.000023	—
Brass	8.2–8.7	1065	2100	0.094	0.000018	—
Copper	8.9	1065	2100	0.095	0.000017	—
Gold	19.3	1065	—	0.0316	0.000014	—
Iron, cast (white)	7.0–7.7	1075–1275	—	0.105	0.000011	—
Iron, wrought	7.8–7.9	1600	—	0.108	0.000012	—
Lead	11.3	327	1400–1600	0.031	0.000028	—
Platinum	21.5	1710–1780	—	0.032	0.000008	0.000025
Silver	10.5	961	2050	0.056	0.000019	—
Steel	About 7.7	1375	—	0.118	0.000011	—
Tin	7.3	232	1450–1600	0.055	0.00002	—
Zinc	7.1	419	918	0.093	0.000029	—
Beeswax	0.96	60–64	—	—	—	—
Coal	1.2–1.8	—	—	—	—	—
Glass, crown	2.6	—	—	0.2	0.000008	0.000025
Glass, flint	3.0–3.6	—	—	0.2	0.000008	0.000025

Properties of Materials — Continued

Substance	Specific Gravity Water = 1	Melting Point ° C.	Boiling Point ° C.	Specific Heat	Coefficient of Expansion	
					Linear	Cubical
Marble	2.5–2.8	—	—	0.21	—	—
Paraffin	0.8–0.9	40–58	—	0.694	—	—
Quartz	2.65	—	—	0.174	—	—
Sulphur, roll	2.0	– 114.5	444.6	0.203	—	—
Alcohol, grain	0.79	– 112.3	78.4	0.547	—	—
Alcohol, wood	0.79	– 95	66	—	—	—
Carbon tetrachloride	1.60	– 19.5	76.7	—	—	—
Ether, sulphuric	0.71	– 112.6	35	—	—	0.0015
Glycerine	1.26	17	290	—	—	0.0005
Kerosene	0.8	—	150–300	0.5–0.6	—	—
Mercury	13.6	– 38.8	357	0.033	—	0.00018
Sulphuric acid, concentrated	1.84	– 29	—	0.332	—	—

III. Density of Water

GRAMS PER CM.^{3}

TEMP. ° C.	DENSITY	TEMP. ° C.	DENSITY	TEMP. ° C.	DENSITY
0°	0.999868	11°	0.999632	21°	0.998019
1	0.999927	12	0.999525	22	0.997797
2	0.999968	13	0.999404	23	0.997565
3	0.999992	14	0.999271	24	0.997323
4	1.000000	15	0.999126	25	0.997071
5	0.999992	16	0.998970	26	0.996810
6	0.999986	17	0.998801	27	0.996539
7	0.999929	18	0.998622	28	0.996259
8	0.999876	19	0.998432	29	0.995971
9	0.999808	20	0.998230	30	0.995673
10	0.999727			100	0.95838

IV. Index of Refraction

Water	1.33	Crown glass	1.51
Alcohol	1.36	Flint glass	1.54 to 1.71
Carbon bisulphide	1.64	Diamond	2.47

V. Electromotive Force of Cells

Simple cell	1.0 volt	Dry cell	1.5 volts
Daniell cell	1.1 volts	Bichromate cell	2.0 volts
Gravity cell	1.1 volts	Storage cell, lead	2.0 volts
Leclanché cell	1.5 volts	Storage cell, Edison	1.2 volts

VI. Table of Natural Sines and Tangents

Angle	Sine	Tangent	Angle	Sine	Tangent	Angle	Sine	Tangent
0	0.000	0.000	31	0.515	0.601	62	0.883	1.881
1	0.017	0.017	32	0.530	0.625	63	0.891	1.963
2	0.035	0.035	33	0.545	0.649	64	0.899	2.050
3	0.052	0.052	34	0.559	0.675	65	0.906	2.145
4	0.070	0.070	35	0.574	0.700	66	0.914	2.246
5	0.087	0.087	36	0.588	0.727	67	0.921	2.356
6	0.105	0.105	37	0.602	0.754	68	0.927	2.475
7	0.122	0.123	38	0.616	0.781	69	0.934	2.605
8	0.139	0.141	39	0.629	0.810	70	0.940	2.747
9	0.156	0.158	40	0.643	0.839	71	0.946	2.904
10	0.174	0.176	41	0.656	0 869	72	0.951	3.078
11	0.191	0.194	42	0.669	0.900	73	0.956	3.271
12	0.208	0.213	43	0.682	0.933	74	0.961	3.487
13	0.225	0.231	44	0.695	0.966	75	0.966	3.732
14	0.242	0.249	45	0.707	1.000	76	0.970	4.011
15	0.259	0.268	46	0.719	1.036	77	0.974	4.331
16	0.276	0.287	47	0.731	1.072	78	0.978	4.705
17	0.292	0.306	48	0.743	1.111	79	0.982	5.145
18	0.309	0.325	49	0.755	1.150	80	0.985	5.671
19	0.326	0.344	50	0.766	1.192	81	0.988	6.314
20	0.342	0.364	51	0.777	1.235	82	0.990	7.115
21	0.358	0.384	52	0.788	1.280	83	0.993	8.144
22	0.375	0.404	53	0.799	1.327	84	0.995	9.514
23	0.391	0.424	54	0.809	1.376	85	0.996	11.43
24	0.407	0.445	55	0.819	1.428	86	0.998	14.30
25	0.423	0.466	56	0.829	1.483	87	0.999	19.08
26	0.438	0.488	57	0.839	1.540	88	0.999	28.64
27	0.454	0.510	58	0.848	1.600	89	1.000	57.29
28	0.469	0.532	59	0.857	1.664	90	1.000	Infinity
29	0.485	0,554	60	0.866	1.732			
30	0.500	0.577	61	0.875	1.804			

VII. Size and Resistance of Annealed Copper Wire

B. & S. Gauge	Diameter in Mils	Area in Circular Mils	Ohms per 1000 Ft. at 20° C.	Feet per Ohm at 20° C.	Feet per Lb., Double Cotton Covered
10	101.89	10,381	0.997	1,003	30.9
11	90.74	8,234	1.257	795.3	38.9
12	80.81	6,530	1.586	630.7	48.8
13	71.96	5,178	1.999	500.1	61.5
14	64.08	4,107	2.521	396.6	77.4
15	57.07	3,257	3.179	314.5	97.2
16	50.82	2,583	4.009	249.4	121.9
17	45.26	2,048	5.055	197.8	153.1
18	40.30	1,624	6.374	156.9	191.5
19	35.89	1,288	8.038	124.4	246.9
20	31.96	1,021	10.14	98.66	297.9
21	28.46	810.1	12.78	78.24	374.5
22	25.35	642.4	16.12	62.05	471.7
23	22.57	509.4	20.32	49.21	584.8
24	20.10	404.0	25.63	39.02	729.8
25	17.90	320.4	32.31	31.29	901.0
26	15.94	254.1	40.75	24.54	1123
27	14.19	201.5	51.38	19.46	1389
28	12.41	159.8	64.79	15.43	1695
29	11.26	126.7	81.70	12.24	2127
30	10.02	100.5	103.0	9.707	2564
36	5.00	25.0	414.2	2.414	6666

It will be noticed that the area of #13 wire closely approximates one half that of #10, and that its resistance is twice as great. Throughout the table, an increase of three numbers corresponds to doubling the resistance, and a decrease of three numbers to halving the resistance.

VIII. Specific Resistance and Temperature Coefficient

(From Timbie's "Elements of Electricity")

Material (Commercial)	Specific Resistance Ohms per Mil-Foot at 20° C.	Temperature Coefficient = $\frac{\textit{Increase per degree C.}}{\textit{Resistance at 0° C.}}$
Aluminum	17.4	0.00435
Copper, annealed	10.4	0.0042
Copper, hard drawn	10.65	——
Iron, annealed	90	0.005
Iron, E. B. B. (Roebling)	64	0.0046
German Silver	114 to 275	0.00025
Manganin	250 to 450	0.00001
Ia Ia (Boker), soft	283	0.000005
Ia Ia (Boker), hard	300	0.00001
Advance (Driver-Harris)	294	0.00000

First Principles of Physics

By Professor HENRY S. CARHART, of the University of Michigan, and H. N. CHUTE, of the Ann Arbor High School. 12mo, cloth, 422 pages. Price, $1.25.

THE present volume is more than a revision of the authors' popular High School Physics. It is a new book from cover to cover. No pains have been spared to make it mechanically the attractive volume which the increasing interest in the applications of this practical subject deserves. The cuts number 457 and will be found to constitute a prominent feature of the book. Especial attention has been given to the language, which has been made unusually simple and direct. The problems are numerous and interesting, and in them the difficulty of the actual arithmetical performance is reduced to a minimum, since it is recognized that the purpose of problems is the concrete illustration of principles rather than practice in arithmetic.

Although in keeping abreast of the times the authors have introduced many new features, they have been careful to retain the general scheme of presentation, and the just proportions, which made their former books so popular. The space given to the various topics is such as logical presentation demands. No topic is unduly emphasized in an effort at novelty of presentation. Each subject is treated concisely and is divided into numerous brief paragraphs with sub-headings, in order to aid the pupil in concentrating his mind on the points of fundamental importance.

It has been felt that many recent text-books in physics have sacrificed scientific and logical presentation in the effort to interest pupils by over-emphasis of some aspect of the science which has been considered attractive. The result of the use of such books has been a one-sided preparation and a consequent failure to meet college requirements. The authors of First Principles of Physics have shown that it is possible to produce a book which is as successful as their former texts in preparing pupils for college and at the same time yields to no competing text-book of physics in attractiveness.

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By H. N. CHUTE, of the High School, Ann Arbor, Michigan. 12mo, flexible cloth, 124 pages. Price, 50 cents.

IN this Manual the author has chosen such problems as his experience has shown to be within the range of the beginner's skill.

There are seventy experiments: (1) those interesting boys and girls alike in the study of physics, (2) those requiring apparatus so simple as to be easily provided, and (3) those illustrating the methods of modern physics. Special attention is devoted to the preparation of the note-book, and for this purpose an unusual array of excellent illustrations is given in the text.

Laboratory Exercises in Physics

By ROBERT W. FULLER and RAYMOND B. BROWNLEE, Stuyvesant High School, New York City. 12mo, cloth, 324 pages. Price, 75 cents.

THIS Laboratory Manual is intended primarily to accompany *Carhart and Chute's First Principles of Physics*, which it follows in the order of subjects. It is so arranged, however, that it can be used with any modern text-book in Physics.

There are ninety experiments in the book. These cover a field so wide that from them may be selected a thorough course which can be given with the apparatus found in any school. At the same time the book affords enough material to satisfy teachers who have the best-equipped laboratories at their disposal.

While the experiments meet the requirements of the College Entrance Board, particular effort has been made to adapt the work to the needs of pupils *not* preparing for college.

The directions are simple and clear, and adapted to the ability of beginners in Physics. There are full instructions on the making of note-books.

First Principles of Chemistry

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THIS book was prepared by the committee of teachers that was called upon to frame the syllabus in Chemistry for New York State. Its three fundamental features are:—

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2. The historical order is followed as far as possible in developing the theory.
3. The practical aspects of the science are emphasized.

In selecting their material the authors have been governed wholly by what they consider its intrinsic value to the elementary student, without reference to its traditional place in a text-book.

To give the pupil some idea of the great commercial importance of chemistry a number of typical manufacturing processes have been described and illustrated. When a substance is manufactured in several ways the authors have given the process most extensively used in this country. The commercial production of copper, aluminum, iron, and carborundum has been described somewhat in detail, as these are notable examples of modern chemical processes.

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IN this manual are included seventy-one experiments, divided into three groups. Group A consists of forty-four experiments which all students should perform. Group B contains quantitative experiments, and Group C includes several extremely interesting experiments dealing with the practical applications of Chemistry.

Household Chemistry for Girls

By J. MAUD BLANCHARD, High School, Los Angeles, California
12mo, cloth, 108 pages. Price, 50 cents.

THE author's purpose is to outline a strong course in chemistry, especially suited to girls of high school age. Though the ultimate aim is the training of intelligent homemakers, it is a manual of chemistry, *not* of domestic science. It is therefore suitable for a purely academic high school, no less than for a polytechnic high school, where a rigorous course in household chemistry forms a necessary foundation for the work in domestic science. The choice of subjects is based in a general way on the following scheme: —

What we breathe.
What we drink and use for cleaning.
What we use for fuels and illuminants.
Chemical nature of common substances.
Foods and food values.
Adulterants and simple methods for their detection.
Textiles — care of textiles, removal of stains, etc.

The second half of the book, beginning with Experiment 28, is devoted to qualitative experiments in organic chemistry, as delicate quantitative experimentation is beyond the ability of high school pupils. Supplementary reading is of course advisable in this connection; with this in view, a full list of library text-books is given, and definite references to these accompany the experiments.

High School Physics

By Professor HENRY S. CARHART, of the University of Michigan, and H. N. CHUTE, of the Ann Arbor High School. New Edition, thoroughly revised. 12mo, cloth, 444 pages. Price, $1.25.

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Part I treats of general physiographic processes. Part II has to do with the physiography of the United States. The book is intended as an aid to study — not as a compendium of information; consequently a description of the world as a whole is omitted. Attention is devoted specifically to the region of the United States, and typical examples afforded by it are studied as representatives of world-wide processes.

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